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# The effects on weapon systems' producibility of suspending system development after Advanced Technology Demonstration (ATD).

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The purpose of this thesis is to analyze the significant effects on producibility of weapons systems caused by suspending system development after prototype development. The focus of this thesis is to develop and recommend appropriate actions that DOD could take to reduce the producibility risk associated with implementation of Advanced Technology Demonstration (ATD) strategies. It includes an analysis of the Defense Science and Technology Strategy Thrust Seven, "Technology for Affordability." It also provides a critical examination of ATD interfaces: SIMNET, CAD/CAM, CIM, CAE, CAPP, CADFM, Rapid Prototyping, and Agile (flexible) Manufacturing. An in depth analysis of Design For Manufacturability (DFM) and its potential effects on program cost is also conducted. Representative producibility assessments performed on the A-12 composite air frame and the Comanche helicopter airframe provide a basis for comparative analysis. The thesis concludes that rapid advances in manufacturing and information technologies offer potentially significant improvements in future RD&A efforts. It recommends that DOD pursue advanced technology enabling methodologies, enhanced (computer aided) systems integration, increased standardization and optimized use of critical manufacturing resources. It also recommends that DOD organize and capitalize a Defense Science and Technology Affordability Research Center (DSTARC).

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# The Effects on Weapon Systems' Producibility of Suspending System Development After Advanced Technology Demonstration (ATD)

by

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Submitted in partial fulfillment
of the requirements for the degree of

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## ABSTRACT

The purpose of this thesis is to analyze the significant effects on producibility of weapon systems caused by suspending system development after prototype development. The focus of this thesis is to develop and recommend appropriate actions that DOD could take to reduce the producibility risk associated with implementation of Advanced Technology Demonstration (ATD) strategies. It includes an analysis of the Defense Science and Technology Strategy Thrust Seven, "Technology for Affordability." It also provides a critical examination of ATD interfaces: SIMNET, CAD/CAM, CIM, CAE, CAPP, CADFM, Rapid Prototyping, and Agile (flexible) Manufacturing. An in-depth analysis of Design For Manufacturability (DFM) and its potential effects on program cost is also conducted. Representative producibility assessments performed on the A-12 composite air frame and the Comanche helicopter airframe provide a basis for comparative analysis. The thesis concludes that rapid advances in manufacturing and information technologies offer potentially significant improvements in future RD&A efforts. It recommends that DOD pursue advanced technology enabling methodologies, enhanced (computer aided) systems integration, increased standardization and optimized use of critical manufacturing resources. It also recommends that DOD organize and capitalize a Defense Science and Technology Affordability Research Center (DSTARC).

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# I. INTRODUCTION

## A. PURPOSE

The purpose of this thesis is to provide an analysis of the significant effects on the producibility of weapon systems caused by suspending system development after prototype development. Since April 1992, the Under Secretary of Defense for Acquisition (USD(A)), and other expert sources, have defined this new flexible acquisition strategy as an Advanced Technology Demonstration (ATD),[1] which was originally posed by the Institute for Defense Analysis (IDA).[2] The focus of this thesis is to develop and recommend appropriate actions that DOD could take to reduce the producibility risk associated with implementation of ATD strategies.

## B. BACKGROUND

On January 29, 1992, the Deputy Secretary of Defense, Mr. Donald J. Atwood, announced adoption of a new flexible weapon systems acquisition strategy. It entailed the flexibility to suspend system development after prototype development

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[1] USD(A) White Paper, *Defense Acquisition,* p.2, May 20, 1992.

[2] IDA Paper P-2444, *The Future of Military R&D: Towards a Flexible Acquisition Strategy*, Institute for Defense Analysis, July 1990.

and place greater emphasis on research and development.[3] The new process could include shelving a developed and prototyped system (suspended development) and freezing the design until the need arises to actually produce the system, based on a perceived threat to national security.

The intent of the new policy was to take advantage of Research and Development (R&D) efforts in the pursuit of advanced science and technology, without committing to the expense of acquiring an advanced weapon system to respond to a greatly diminished national security threat. This policy could have the following advantages:

- Significant cost savings to DOD
- Continued advancement of US science and technology bases for future defense needs.
- Commercial (dual) uses.
- Significantly reduced lead time.
- Extra "breathing room" for engineers in various disciplines to refine production processes and manufacturability issues, particularly those involving state of the art technology and advanced composite materials.
- Reduce potential delays and costs associated with software development.
- Reduced concurrency in weapon systems' acquisition strategies, driven by the prior need to get weapon systems to production and deployment as soon as possible, to counter the Soviet Threat.

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[3] DOD Budget Briefing, Secretary of Defense Richard Cheney, Deputy Secretary of Defense Donald Atwood, and General Colin Powell, Chairman, JCS, Wednesday, January 29, 1992, 1:00 p.m., script released by OASD (Public Affairs).

The USD(A) stated:

> In addition, with the breakup of the Warsaw Pact and the dissolution of the Soviet Union, the pressure of rapidly advancing high technology weapons in the arsenals of potential enemies has also significantly lessened. Consequently, the need to replace existing weapons systems in order to maintain a significant technological advantage is no longer as urgent. As a result, we will be able to reduce concurrency in development programs and retain existing equipment for longer periods, with necessary technological advances incorporated more often through upgrades than through initiation of new systems.[4]

The new flexible acquisition strategy could also have the following disadvantages:

- Increased learning curve costs associated with industry loss of technical expertise.
- Obsolescence of design and critical components (e.g., electronics, avionics, fire control and advanced materials).
- Obsolescence of systems currently in use.
- Lower tier manufacturers leaving the defense industrial base.

Considering the fact that "a major portion of the projected life-cycle cost for a given system or product stems from the consequences of decisions made during early planning and as part of system conceptual design (Concept Exploration),"[5] we must carefully consider the impact of the peculiarities of this acquisition strategy early on

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[4] USD(A) White Paper, *Defense Acquisition*, p.1, May 20, 1992.

[5] Benjamin S. Blanchard and Wolter J. Fabrycky, *Systems Engineering and Analysis*, p. 505, Prentice Hall, Englewood Cliffs, New Jersey, 1990, (Cost Emphasis in the System Life Cycle).

in development. Processes like "Design For Manufacturability (DFM)"[6] might aid in reducing those potential costs and associated producibility risks. Proceeding with LRIP before "shelving" or "hovering" the system design might also help to reduce those risks.

The greatest risk associated with the ATD strategy may be the losses in DOD's weapons acquisition capability, resulting from the reduction in the depth and breadth of the defense industrial base. Expertise lost in this highly technical and world wide, competitive industry would be very difficult, time consuming and costly to redevelop. We might also see a significant increase in the cost of R&D, considering the increased uncertainty of a production profit incentive for manufacturers. As stated in a House Armed Services Committee (HASC) report:

> To compound the problem, industry investment in research and development [R&D] is expected to decline as defense procurement declines. Production equals profits -- it justifies the investment in research and development. As production declines so will R&D, with devastating effects for the US defense industrial base -- unless we are able to assure firms a profit from their research.[7]

It is questionable, especially considering the current and projected reductions in the defense budget, whether lower tier manufacturers in the defense industry could

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[6] Vol. 6, Tool and Manufacturing Engineers' Handbook (TMEH), *Design for Manufacturability*, Society of Manufacturing Engineers, McGraw Hill, January 1992.

[7] Report of the Structure of US Defense Industrial Base Panel, *Future of the Defense Industrial Base*, p.8, HASC, April 7, 1992 .

afford to stay in this industry while these systems remain "on the shelf" or "hovering" for any length of time.

Recent USD(A) publications define science and technology producibility in the broad sense of "Affordability" (Science and Technology (S&T) Thrust Seven). The Defense Science and Technology Strategy states that:

> A central tenet of the S&T strategy is that technology will be guided toward specific capabilities that can be proven with an Advanced Technology Demonstration (ATD). Such a demonstration of capability, coupled with simulations and exercises, will help to ensure that the technology is ready, manufacturing processes are available, and operating concepts are understood, before a formal acquisition program is undertaken.[8]

Although the USD(A) strongly supports "Integrated Product and Process Development" (IPPD) and has published and espoused much on the philosophy, little has been published that provides methodical approaches.[9]

Given the apparent decline in fiscal trends, we must find more efficient and effective means to advance defense science and technology, and to develop advanced weapon systems. OSD's (Office of the Secretary of Defense) new flexible acquisition strategy may help to provide some methods for solving some of these problems.

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[8] DDRE, *Defense Science and Technology Strategy*, p.2, July 1992, Executive Summary.

[9] Based on conversation in January 1992 with Mr. T. Daniel Cundiff, Industrial Specialist, OASD(P&L) Production Resources and Manufacturing Modernization.

## C. THESIS OBJECTIVES

The primary objective of this thesis is to analyze and propose methods that might be useful in reducing the risk associated with ATD producibility. Therefore, it will focus on three specific areas: (1) integrated ATD (product) and process development, (2) integrated DFM, and (3) potentially innovative solutions to producibility risk reduction and process development. The thesis culminates in proposals designed to enhance the affordability and IPPD of an ATD. The proposals presented and analyzed are not all encompassing, nor exhaustive.

## D. RESEARCH QUESTIONS

### 1. Primary Research Question

What are the significant effects on the producibility of weapon systems that result from suspending system development after Advanced Technology Demonstration (ATD)?

### 2. Subsidiary Research Questions

a. What is an Advanced Technology Demonstration (ATD)?

b. What is Design for Manufacturability (DFM)?

c. Should DFM be used in an ATD, and if so, when should it be used and what are the potential effects?

d. How can DOD ensure the producibility of an ATD?

e. How should DOD manage the development of manufacturing processes in an ATD?

## E. RESEARCH SCOPE AND LIMITATIONS

This thesis examines elements of the new Research, Development and Acquisition (RD&A) strategy from the distinct perspective of producibility and transition to production. It includes an analysis of how an ATD fits into a typical acquisition strategy and what key issues are associated with the transition from an ATD to acquisition program. It addresses the Society of Manufacturing Engineers' DFM concept in terms of ATD development and potential benefits. It also includes issues associated with Integrated Product and Process Development (IPPD) of an ATD.

In order to analyze real producibility issues, the research included an examination of the A-12 and LHX (Comanche) programs from a producibility perspective, particularly since cutting edge technology is involved in both programs. This examination was not exhaustive, and was limited only to pertinent producibility and design issues.

## F. RESEARCH METHODOLOGY

Pertinent literature was requested through the Naval Postgraduate School library. This included periodicals, technical reports and publications, policy documents, and text books. These materials were thoroughly reviewed.

Some key elements of the thesis research was conducted by telephonic interviews with Government and industry program offices, DSMC subject matter experts, and USD(A) officials. The majority of the research was derived from careful review of materials on design for manufacturability, producibility analysis, flexible manufacturing, rapid prototyping, CIM, and CAD/CAM based on periodicals, texts and handbooks.

Interviews were also conducted with professors and other subject matter experts concerning Virtual Environments, Virtual Prototyping, "Virtual Production"[10] and SIMNET, both telephonically and in person. Much information was obtained from guest speakers during the Program Management Seminar at the Naval Postgraduate School.

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[10] "Virtual Production" is an idea posed by Mr. Bob Warren, DSMC, in a conversation on October 15, 1992.

# II. BACKGROUND AND RECENT DEVELOPMENTS

## A. THE PROBLEM WITH SYSTEM PRODUCIBILITY

Historically, producibility has been a design requirement under Military Standard 1528A, Manufacturing Management Program. Only recently, has DOD begun to understand its importance. It is critical to consider producibility, up front, in the design process. The Department of the Navy stated in its *Best Practices* manual:

> Besides the more obvious performance and reliability requirements, there is the additional demand of producibility: it must be economically feasible to manufacture a quality product at a specified rate and to deliver end items capable of achieving the performance and reliability inherent in the design. This design requirement is not always well understood and historically has taken a back seat to the more popular objective of high performance. The results of this neglect have ranged from factory rework rates in excess of 50 percent to suspension of government acceptance of end items pending major redesign for producibility. A strong producibility emphasis early in design will minimize the time and cost required for successful transition to production.[11]

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[11] Department of the Navy, NAVSO P-6071, *Best Practices: How to Avoid Surprises in the World's Most Complicated Technical Process - The Transition from Development to Production*, p. 4-11, Reliability, Maintainability and Quality Assurance Directorate, March 1986.

The Defense Systems Management College defines producibility as:

> The relative ease of manufacturing an item or system. This is governed by the characteristics and features of a design that enable economical fabrication, assembly, inspection, and testing using available manufacturing techniques.[12]

In *Producibility Measurement for DOD Contracts*, producibility is simply a question the Government Program Management (PM) office should ask when evaluating proposals: "Does the company have the capability and commitment to design and manufacture the product so it can be made in quantity with a high degree of quality, reliability, and maintainability in the finished item?"[13] (There are many other aspects involved in the definition of producibility, which will be addressed more in depth in Chapter IV, DFM.) Despite how one chooses to define the term, many in DOD recognize it as an essential requirement to consider in the design process. DSMC suggests that, during the Concept Exploration/Definition (CE/D) Phase,

> The program manager should ensure that a manufacturing feasibility assessment is accomplished in the initial phases of product development. Feasibility estimates determine the likelihood that a system design concept can

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[12] Defense Systems Management College, *Glossary: Defense Acquisition Acronyms & Terms*, p. B-83, Acquisition Policy Department, Fort Belvoir, Virginia, Fifth Edition, September 1991.

[13] Office of the Assistant Secretary of the Navy (Research, Development and Acquisition) PI, *Producibility Measurement for DOD Contracts, or "How can I make what the government wants without losing my shirt?"*, Best Manufacturing Practices Program, Washington, D.C., 1992. The handbook was published in coordination with the US Army Materiel Command, as well as the Department of the Air Force, Office of the Assistant For Reliability, Maintainability, Manufacturing and Quality.

be produced using existing manufacturing technology while simultaneously meeting quality, production rate and cost requirements.[14]

Unfortunately, the Services' acquisition executives and program/project managers (PMs) have not always planned for producibility analysis in programs to avoid potential producibility problems. Waiting until problems arise is too late.

One program, in recent years, is an excellent example of poor producibility analysis during design - the Navy's canceled A-12 program. The Beach Report[15] identified many problems in the management of the A-12 program. At no point in the report did Beach single out inadequate producibility analysis and planning in system design as a "culprit" in the program; however, this was evidently the case. The report states:

> The primary problem encountered during FSD was weight growth due to the thickness of the composite material necessary for the structural strength required to support the stress and loads experienced by carrier-based aircraft. Both contractors have had limited experience in building large composite structures and, in large measure, have had to develop the technology as the program progressed.[16]

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[14] DSMC, *Defense Manufacturing Management Guide for Program Managers*, p. 3-6, Third Edition, Fort Belvoir, Virginia, April 1989. DSMC also points out that "the feasibility analysis involves the evaluation of: (1) producibility of the potential design concepts, (2) critical manufacturing processes and special tooling development which will be required, (3) test and demonstration required for new materials, (4) alternate design approaches within the individual concepts, and (5) anticipated manufacturing risks and potential cost and schedule impacts."

[15] Chester Paul Beach, Jr., Memorandum for the Secretary of the Navy, SUBJ: A-12 Admininstrative Inquiry, November 28, 1990.

[16] Ibid., p. 8.

Although producibility analysis (or more appropriately design for manufacturability (DFM)) may not have greatly affected the weight growth problem involving composite materials, it would have been a factor in the selection of the design materials. The fact that both McDonnell Douglas and General Dynamics had very limited experience in manufacturing processes for large composite structures, should have been considered in the Navy's decision process. A fixed-price contract restricts many decisions, making issues such as material selection in the design highly significant. The EMD phase is not a good time to discover that a contractor (or team) does not possess adequate manufacturing process capabilities to produce a weapon system according to requirements.

Beach identified five areas where the Program Manager "underestimated the cost implications of adverse engineering and manufacturing process data":

- the impact of the late release of detailed design drawings on manufacturing, particularly on the contractor's ability to facilitate initial tool design and fabrication of tooling to support assembly operations and piece part fabrication.

- the instability of the design releases to manufacturing.

- the high degree of design change notice activity and the resulting stop work orders to manufacturing, which delayed tool design and fabrication and initial piece part fabrication.

- the impact that the late start on tool design and fabrication, for both assembly and piece part fabrication tooling, would have on the proposed schedules.

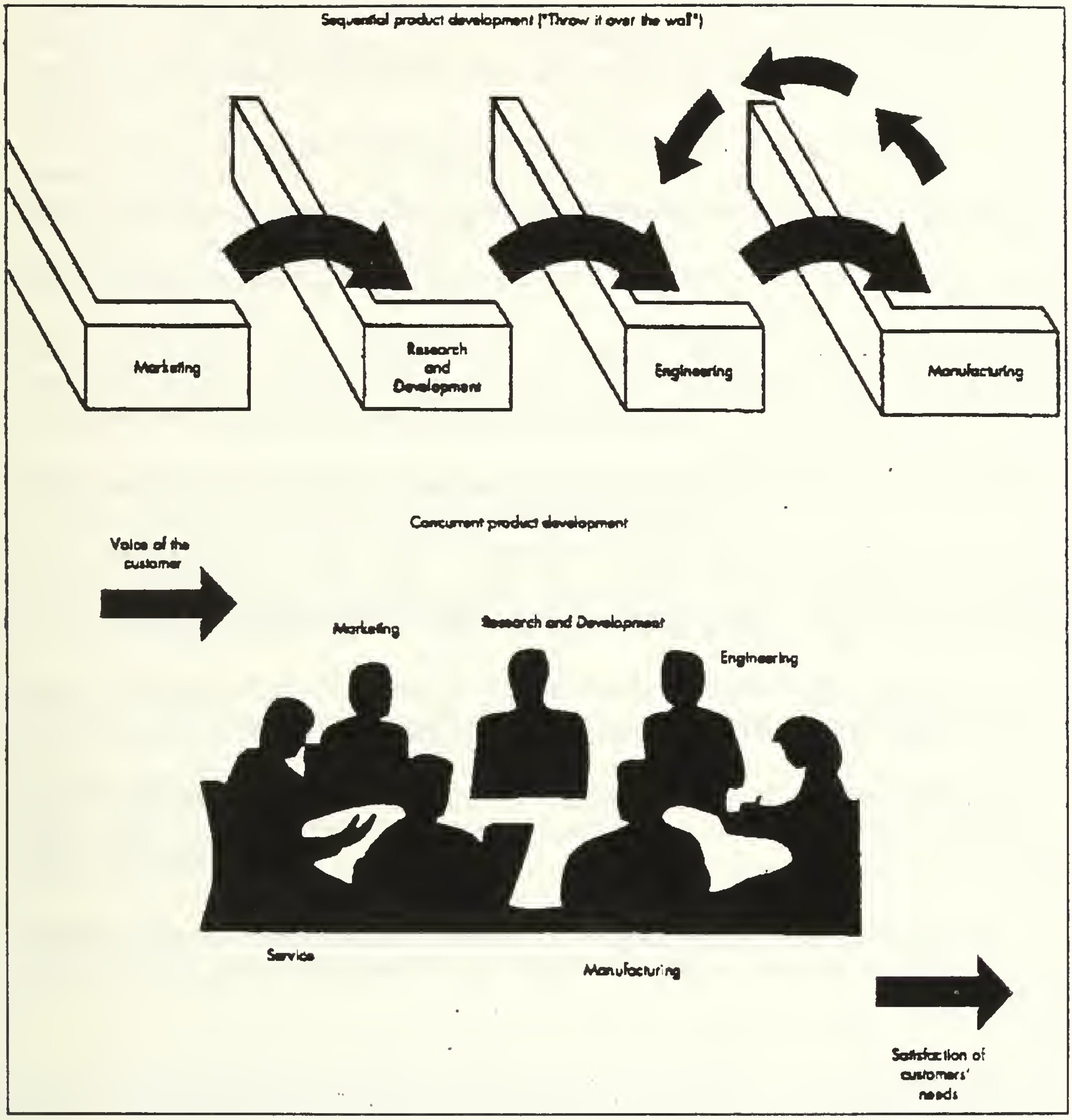


**Figure 1** Concurrent vs. Sequential Engineering (TMEH, Vol. VI, p. 1-12)

- the inability of the contractors' tool shop/outside vendors to support initial fabrication of piece parts necessary to sustain asserted assembly schedules.[17]

[17] Ibid., p. 12.

One issue here makes it clear that the PM did not emphasize producibility during the development process. McAir and General Dynamics used a sequential (functionally non-integrated and non-simultaneous) engineering approach, rather than a concurrent (functionally and simultaneously integrated) engineering approach. (See Figure 1 obtained from the Tool and Manufacturing Engineers Handbook (TMEH) Vol. VI.)

"Manufacturing" was not involved in the design, which is essential in designing a complicated system involving advanced technology. The outcome of the A-12 program may have been significantly different. Therefore, this issue will be addressed, in detail, in Chapter IV, Design For Manufacturability.

## B. THE NEW "FLEXIBLE" ACQUISITION STRATEGY

The Institute for Defense Analyses (IDA) first introduced the idea of a "flexible" acquisition strategy in July 1990 in the study, *The Future of Military R&D: Towards a Flexible Acquisition Strategy*.[18] IDA's recommendations[19] in the report are as follows:

> **Recommendation 1:** DOD should reaffirm that maintaining superior technological options remains a vital strategic objective. [This is reflected in the 1992 National Military Strategy.]

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[18] IDA Paper P-2444, *The Future of Military R&D: Towards a Flexible Acquisition Strategy*, Institute for Defense Analyses, July 1990.

[19] IDA Paper P-2444, *The Future of Military R&D: Towards a Flexible Acquisition Strategy*, pp. 4 - 5. Institute for Defense Analyses, July 1990.

**Recommendation 2a:** Funding for science and technology (S&T) should increase. [Although there was no real increase in funding in the FY93 appropriation bill, S&T was not subjected to cuts as were other areas of the defense budget.]

**Recommendation 2b:** The DOD science and technology program and laboratory system have fundamental management problems which must be addressed immediately. [Addressed in the new Defense Science and Technology Strategy (1992).]

**Recommendation 2c:** DOD's R&D resources should remain focused on military needs. [Although there may be a more significant shift toward "dual use" technology under the current administration.]

**Recommendation 3:** DOD should treat R&D as a product in its own right. [As reflected in the DOD Key Technologies Plan (1992).]

**Recommendation 4:** Increase the use of prototyping. [Introduction of the advanced technology demonstration (ATD) concept.]

**Recommendation 5:** Improve the development of technological options for modifying existing systems. [A key element of the ATD approach.]

**Recommendation 6:** Increase the use of commercially available technology. [As used in the reconstitution concept, addressed in the National Military Strategy (1992).]

**Recommendation 7:** Weapon system designs must consider the need for mobilization. [Also addressed in the National Military Strategy (1992).]

The current fiscal constraints on the DOD budget have brought increased emphasis on recommendations three and four regarding the role of ATDs and technology insertion. Two parts of the study in particular were integrated into DOD's new R&D strategy:

Under a flexible acquisition process, a decision early in the pipeline to proceed with a set of technologies or a system concept would not constitute a

determination that a specific system would, in fact, go to full scale production. . . . In addition, technological developments in subsystems and components could be available for introduction into existing systems (product improvements) [or technology insertions] without having to commit to a new system entering production. The R&D and acquisition process would be geared to four major types of developments: (1) modification to existing equipment in the field, (2) improvements to and modernizations of systems currently in production, (3) new product developments, and (4) designs and design modifications which allow for rapid production in the event of a mobilization [one of the key tenets of the R&D strategy addressed in the National Military Strategy (1992)].[20]

Providing advice about how this should be carried out, IDA stated:

Under a flexible acquisition strategy, numerous options would be explored from research (6.1) through advanced development (6.3A). Programs would enter full scale development [EMD] (6.4) less often and more selectively, and not every 6.4 development program would be expected to make it into production.[21]

IDA went into much more detail and defined prototyping as "technology demonstrators" which were much more than "just pre-production items manufactured in FSD." IDA went to great lengths to include the issues of "product improvements" and prototypes of new weapon systems concepts.[22]

One relevant strength of the new process involves "the potential impact of longer design periods." The report states specifically:

One byproduct of increasing the use of prototyping and having fewer systems in production will be an increase in the amount of time between production

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[20] Ibid., p. 3.

[21] Ibid., p.4.

[22] Ibid., pp. 15 - 16.

decisions for weapon systems, and thus an easing of the time pressure to attain an initial operating capability (IOC). In other words, a system or sub-system might be designed, but a decision may be made to hold off on its production. This would provide a longer window of opportunity to mature the design and test it in realistic operational environments, and could allow for greater attention to producibility, maintainability and other manufacturing and support considerations. To put it another way, by easing the time pressures faced by designers, increased attention could be placed on reducing the eventual cost of a product. At the same time, with existing systems staying in the field longer, increased attention could be paid by designers to cost effective means of introducing product improvements.[23]

The idea of putting off the production decision until a technology has been "matured" has evolved into talk of "shelving" the system. It is not readily apparent when analyzing the study, that shelving was their intent for an ATD. The previous quotation suggests the opposite. DOD's intent becomes more of relieving the time pressure tô field a system to devote more effort into the "affordability" aspects, especially in the area of producibility. Given the change in "threat" to national security, this appears even more plausible.

The IDA study also posed a remarkable, revolutionary benefit:

> . . . Second, advanced simulation and other technologies make it possible to test ideas in far more realistic and effective manned simulators and wargames than in the past. These technologies can be used to test proposed changes in components, subsystems, or systems before complete prototype systems are constructed, saving considerable time and expense.[24]

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23 Ibid., pp. 16 - 17.

24 Ibid., p. 17.

Excellent examples of this approach are "virtual prototyping," (being pursued vigorously at the US Army Tank Automotive Command, R&D Center in Warren, Michigan) as well as the NPSNET (simulation network) at the Naval Postgraduate School. (These areas are addressed in more detail in Chapter III, *The New S&T Strategy*.) Advances in these areas are increasing exponentially. This area holds such significant potential, that the Director of Defense Research and Engineering (DDRE) included "Synthetic Environments" as Science and Technology (S&T) Thrust Six in the Defense Science and Technology Strategy.[25]

## C. ANNOUNCING THE FLEXIBLE ACQUISITION STRATEGY

On the same day (January 29, 1992) that former Deputy Secretary of Defense Donald J. Atwood announced that DOD would pursue a new approach to weapon systems acquisition, former Secretary of Defense Richard (Dick) Cheney stated in a press conference:

> When we talk about prototyping, we are not talking about sort of building one of something and putting it on the shelf. We well understand that the process of developing a new weapon system involves not only developing the technology and engineering it into a weapon, it also involves developing the production process and understanding the manufacturing process that would allow you to produce it in significant numbers.[26]

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[25] DDRE, *Defense Science and Technology Strategy*, p. ES-3, July 1992.

[26] Charles B. Cochrane, *DOD's New Acquisition Approach: Myth or Reality*, quote of Richard Cheney from January 29, 1992 press conference, p. 40, Program Manager, July-August 1992.

The most critical aspect of the new flexible acquisition strategy, as pointed out by former Secretary Cheney, is "developing the production process and understanding the manufacturing process that would allow you to produce it in significant numbers." Without having developed the manufacturing processes fully, a program would probably encounter the same technical difficulties as the Navy's canceled A-12 program.

This requirement should go far beyond just developing the manufacturing process. It is frequently overlooked and misunderstood that the best way to prevent such problems is to incorporate the right processes up front, during concept design. Striving to develop the manufacturing processes involved in a new weapon system is important, but is an attempt to "treat the symptom" of not having adopted an adequate process philosophy, up front in the program. Any materiel R&D program must incorporate a concurrent engineering approach involving DFM to be successful in these fiscally constrained times. (This is addressed in detail in Chapter IV, *DFM*.)

During the January 29, 1992 press conference, former Secretary Cheney went on to say:

> It also involves building enough of a particular item to get operational experience with it, to be able to field it with the force in sufficient numbers so that we can develop the doctrine that goes with it . . . We are not talking about just building one or two items and putting them on the shelf.[27]

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[27] Ibid., p. 40.

The former Assistant Secretary of the Army for Research, Development and Acquisition (ASA(RDA)), Mr. Stephen J. Conver, most eloquently emphasized this point, in a draft working paper on *Shaping the Defense Industrial Base of the Future:*

> The lesson here is clear -- technological superiority is necessary, but it is not sufficient to guarantee quick and decisive combat victory with minimum casualties. Future wars are likely to be "come as you are" affairs; the existence of superior technology in the laboratories will be of no use in winning in those engagements.[28]

Mr. Conver effectively argues his point using Army "Task Force Smith," early in the Korean War, as a stark and haunting example. He points out poor training and poor equipment as the chief causes of the task force having been severely mauled by the North Koreans. He said: "In retrospect, no one would claim that North Korea was <u>technologically</u> superior to the United States in 1951; however, North Korea was able to bring superior capabilities to bear because, at that time and place, they had a clear superiority in their <u>fielded equipment</u>."[29] The Chief of Staff of the Army, General Sullivan, put US Army concerns most succinctly: "No more Task Force Smiths!"

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[28] Stephen K. Conver, ASA(RDA) draft working paper, *Shaping the Defense Industrial Base of the Future*, p. 4, received via fax at NPS on November 10, 1992.

[29] Ibid., p. 4.

## D. THE NATIONAL MILITARY STRATEGY

The Joint Chiefs of Staff (JCS) have also adopted this new, flexible acquisition strategy into our national military strategy. Regarding R&D, it states:

> Since we currently have the most technologically advanced systems in the world, our future investment choices may require a different acquisition strategy than we have followed in the past. For example, full scale production may not always follow prototyping. We need to protect the capability to produce the world's most technologically advanced weapons systems, but only if required.[30]

To provide a "safety net" for our technological edge, the JCS have adopted the concept known as "Reconstitution" (see recommendation 6 on page 15) into the National Military Strategy as well.[31] In summary, the idea of "reconstitution" requires early strategic warning of a potential threat to national security. An early strategic warning of a threat then triggers a "Graduated Mobilization Response." The key here is the fact that there is no world power with significant capabilities to pose a threat to the United States' security without (1) early strategic warning, and (2) a period of at least five years to present such a threat.

The concept of reconstitution of US military forces, forms a part of the foundation of the new flexible acquisition process. As Secretary Cheney pointed out (see page 18), it is critical to be able to "produce it [ATD] in significant numbers." There are potential significant problems with suspending EMD and production of an

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[30] *1992 National Military Strategy*, p. 25, JCS, 1992.

[31] Ibid., p. 25.

ATD: (1) The capability to produce a prototype does not guarantee the capability to "produce it in significant numbers, and (2) there exists a potential for weapon systems' component obsolescence as a function of time suspended or "on the shelf."

Generally, a prototype is manufactured, hands-on, by the engineers assigned to a given project. These engineers attend to every minute detail, such as fit and trim, bonds and fastenings, coatings, etc. Just because a prototype can be manufactured does not mean that the system can be economically produced in "significant numbers." Usually, the processes used to manufacture a prototype are considered "soft" tooling; the processes used on the production line are considered "hard" tooling. It is critical during the design process, to consider production line process capabilities during design analysis and decision making. (This concept will be addressed more fully in Chapter IV - *DFM*.)

Another critical aspect associated with suspending system development prior to production is that of potential component obsolescence. This is especially a problem in electronics and avionics. Specific electronic components, possessing given performance properties, used in the design of components and sub-systems are usually selected based on market or current "state of the art" availability (excluding Applications Specific Integrated Circuits or ASIC). Electronic technological development is accelerating so rapidly, that what is readily available on the market today, may not be readily available two years from today.

A good example of this is the 8088 and 80286 processors. These were state of the art only a few years ago. Microchip manufacturers are only making 80386 and 80486 processors today. Although the industry could go back and produce the old components, the added costs, and obsolete capabilities would not be cost effective.

Therefore, the concept of "reconstitution" may need to include a policy of perpetual market surveillance and design review. Otherwise, what may be "existing commercial capability" today, may not be economically producible (affordable) tomorrow.

## E. POLICY IMPLEMENTATION AND THE DEFENSE INDUSTRIAL BASE

On May 20, 1992, Donald Yockey, then Under Secretary of Defense for Acquisition (USD(A)), released four white papers that described in detail, various aspects of the new acquisition strategy. The impact of the new acquisition strategy was, as Mr. Yockey pointed out in the cover memorandum:

> Although the most immediate impact of the revised approach was on the ten major acquisition programs adjusted in the FY 1993 Amended President's Budget, all programs will be managed in accordance with this approach. The Secretaries of the Military Departments should review existing acquisition programs to determine which programs should be restructured to reflect the revised approach, if they have not already done so.[32]

The last statement (above) indicated that all programs will be managed using the new approach and that Mr. Yockey wanted the Secretaries of the Military

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[32] USD(A) White Paper Memorandum, Mr. Donald Yockey, May 20, 1992.

Departments to nominate existing programs to be restructured accordingly. The Comanche (RAH-66) helicopter is one of the programs that underwent restructuring during August to December 1992. Pertinent elements of the Comanche program are addressed in Chapter IV (*DFM*).

The first White Paper titled, *Defense Acquisition*, reiterated the January 1992 policy change announcements and many proposals from the original 1990 IDA study. Prior to the USD(A) White Papers, there was much public discussion about the effects of suspending the development of an acquisition program after prototype development and testing. "Putting the system on the shelf" was the term that was being used most frequently (alluded to by former Secretary Cheney (see page 18)). The concept of putting a partially developed system "on the shelf" was apparently the weakest aspect of the new flexible acquisition strategy. (See detailed discussion in Chapter V.) This concept was openly attacked in Defense oriented publications, particularly in articles in the *Defense News*. It seems that the term "putting it on the shelf" has become a near "taboo" in OSD because of the weakness. Despite what we call it, the weakness may persist.

To support the concept of reconstitution, the USD(A) White Paper, titled *Defense Industrial Base,* also sets forth an objective that is critical to the new strategy. It states that "the industrial base must be able to build up production capacity faster

than any newly emerging global threat can build up its capacity."[33] This is essential to US national security given the new flexible acquisition strategy. This document also reemphasizes the policy of "continuing to develop new and innovative manufacturing technologies to improve the efficiency of production," to enhance potential systems' affordability.

The *Defense Industrial Base* White Paper also establishes investment priorities in new manufacturing processes and methodology:

> DOD is pursuing a specific thrust area within the Science and Technology Program entitled Technology for Affordability. This initiative examines new technologies for time, cost, and production efficiencies concerning hardware/software prototyping, flexible production capabilities, and advanced manufacturing processes. This process-oriented thrust supports the development of new product technologies within the Science and Technology strategy.
>
> The Department is committed to expanded research and development to make manufacturing processes more flexible. Flexible manufacturing processes can be adapted to produce more than one type of item. This makes the production of a smaller number of each type of item more efficient, which will reduce reliance on economies of scale. It also has the potential to provide entirely new manufacturing methods which could replace existing critical processes.

This is an extremely dynamic dimension of the new strategy. Many advances in manufacturing technologies have been made in the past few years, and are rapidly emerging on the horizon; however, DOD must be careful not to depend excessively on the prospects of flexible (agile) manufacturing capabilities to bring success to the

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[33] USD(A) White Paper, *Defense Industrial Base*, p. 2, May 20, 1992.

new acquisition strategy. While many strides have been made in Distributed Numerical Control (DNC) integrating numerically controlled machinery in industry, particularly in handling conventional industrial materials, much work remains to be done in flexible electronics and flexible composite manufacturing technologies.

Still, significant advances in these areas appear plausible. Advances in robotic assembly accuracy for use in manufacturing electronic devices improve the potential for flexible electronic manufacturing capability. It is also remarkable to note that advances made in fiber based rapid prototyping systems has potential expandability into composite pultrusion processes.

## F. THE DEFENSE SCIENCE AND TECHNOLOGY STRATEGY

The USD(A) White Paper, *Defense Science and Technology Strategy*, focuses on seven Science and Technology (S&T) thrusts,[34] which represent DOD's of the US military's most critical needs:

1. **Global Surveillance and Communications.**
2. **Precision Strike.**
3. **Air Superiority and Defense.**
4. **Sea Control and Undersea Superiority.**
5. **Advanced Land Combat.**

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[34] USD(A) White Paper, *Defense Science and Technology Strategy*, pp. 3 - 4, May 1992.

6. **Synthetic Environments.**

7. **Technology for Affordability.**

Figure 2 is a graphic representation of the overall S&T concept. Note that Thrust Six (Synthetic Environments) and Thrust Seven (Technology for Affordability) provide a foundation for developing thrusts one through five.

The White Paper states:

> A central tenet of the S&T strategy is that technology will be focussed toward specific capabilities that can be proven with an Advanced Technology Demonstration (ATD). There are generally two types of ATDs: those focused on new system and subsystem concepts [thrusts one through five] and those focused on "enabling" technologies [thrusts six and seven]. Demonstrations of capability, coupled with simulations and exercises, will help to ensure that the technology is ready and affordable, manufacturing processes are available, and operating concepts are understood before committing to a formal acquisition program.[35]

Thrust six, Synthetic Environments, is an enabling technology that provides an extensive medium for bringing the user into a "feed forward/feed back" loop interconnected with the R&D community in an effort to solve problems involving military needs. The idea is to use expanded, simulated and integrated environments to provide analogous instrumented training and testing ranges, and electronic battlefields.

Thrust seven, Technology for Affordability is described in the White Paper as:

> Technologies that reduce unit and life cycle costs . . . . Advances are particularly needed in technologies to support integrated product and process

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[35] Ibid., pp. 2 - 3.

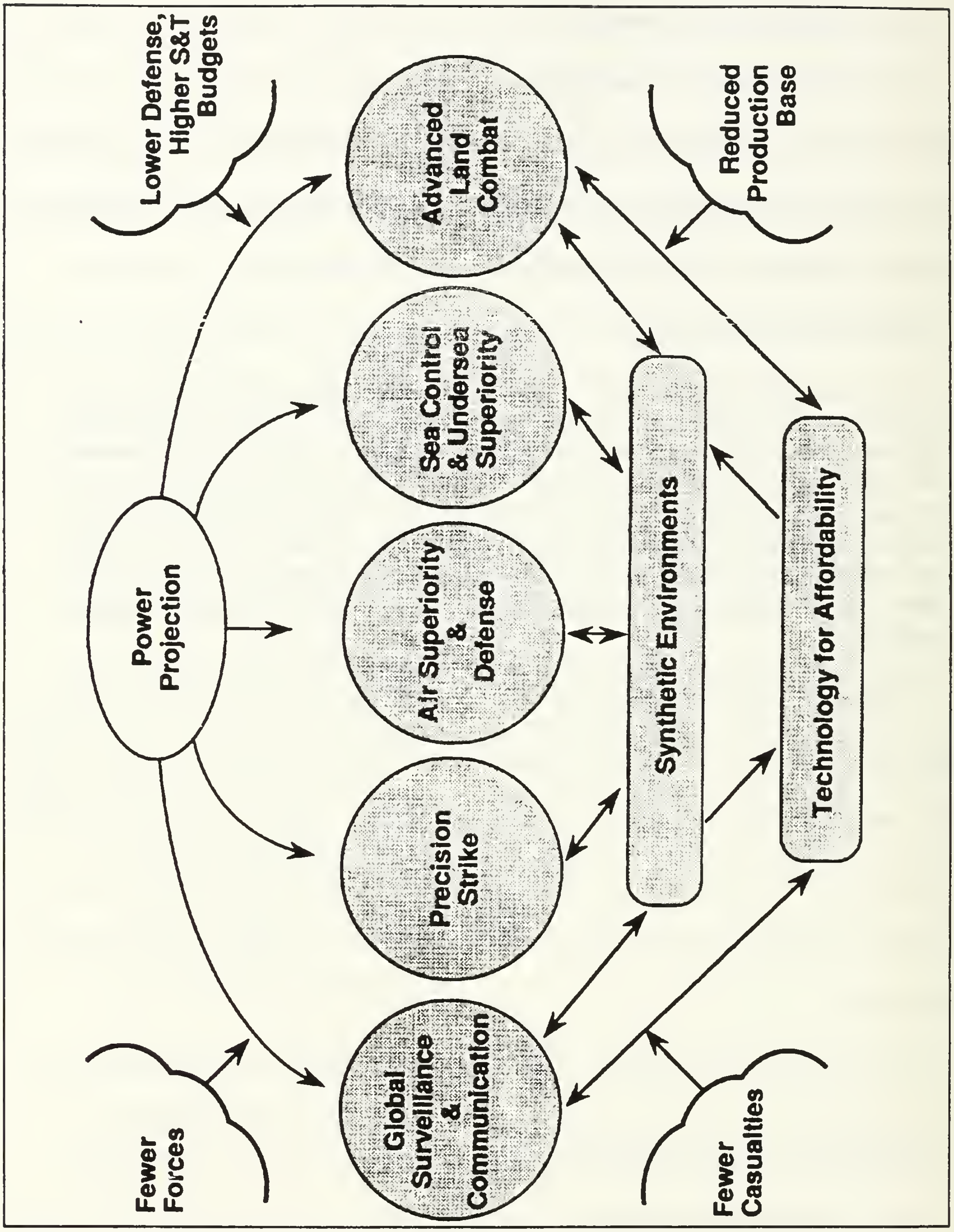


**Figure 2** Defense S&T Strategy: Seven Thrusts (p. I-19)

> design, flexible manufacturing systems that separate cost from volume, enterprise-wide information systems that improve program control and reduce overhead costs, and integrated software engineering environments.[36]

Flexible manufacturing systems and synthetic environments may provide a significant cost effective method for developing and evaluating Advanced Technology Demonstrations. It is questionable whether technological developments will be adequate to achieve S&T objectives in this area. Chapter IV (*DFM)* examines this question in terms of important paradigm shifts to increase the probability of success in affordability efforts.

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[36] Ibid., p.4.

# III. THE NEW SCIENCE AND TECHNOLOGY STRATEGY

## A. ADVANCED TECHNOLOGY DEMONSTRATION (ATD)

When the new flexible acquisition strategy was introduced, much of the discussion surrounded the use of "prototyping" in the new strategy. Since January 1992, USD(A) has published several documents that further define the concept. Today, the term "prototype" applies only to acquisition programs. Under the new S&T strategy, only the term Advanced Technology Demonstration describes the function formerly associated with a prototype.

The USD(A) White Paper establishes a distinction between "ATDs and acquisition system activities":

> The key distinction between ATDs and acquisition system activities is that the former are part of the science and technology base and are focused on validating the viability and producibility of a technology. The acquisition system activities on the other hand, are undertaken only when the following criteria are met:
>
> - The technologies have been demonstrated, thoroughly tested, and shown to be producible.
> - There is a clear and verified military need for the new system or system upgrade.
> - The new system or system upgrade is cost effective.

> Systems that meet these criteria will enter the acquisition cycle and, in addition to supporting our base force, will engage the defense industrial base in modern production activities.[37]

According to this document, transition from an ATD to the acquisition cycle is predicated on producibility of the system, the military need for the system and the cost effectiveness of the system. Initially, this seems straightforward; however, the policy is not as clear when some work still needs to be done on some manufacturing processes (e.g., composite airframe) and the military need is not immediately identifiable. The question arises: What should be done if, upon ATD system progress review, it is not yet producible and the military need is not yet clear? A decision must be made whether to continue to develop the system (requiring additional funds), abandon it or "put it on the shelf."

The Defense S&T Strategy states:

> A primary objective of the new acquisition approach is to conduct more rigorous "up-front" technology developments so that the formal acquisition cycle can be made less risky. Technologies will remain in the S&T program until they are fully matured and ready for application to upgrades of existing systems or to a new system.[38]

This objective makes sense, considering the breakup of the Soviet Union and the concomitant reduced threat. Racing to get a system fielded because of the threat posed by our "adversary" is no longer a critical issue. However, DOD should caveat

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[37] USD(A) White Paper, *Defense Acquisition*, p. 3, May 20, 1992.

[38] DDRE, *Defense Science and Technology Strategy*, p. I-16, July 1992.

the last sentence in the above quotation. "Technologies will remain in the S&T program" as long as Congress and the Administration continues funding "until they are fully matured . . . ." Figure 3 is a visualization of the new strategy.

In the new strategy, simulations and exercises are used to develop not only technical requirements, but issues involving tactics, doctrine and structure as well. Issues identified during simulations and exercises are incorporated by various means into the ATDs. This process continues, increasing knowledge in both operational and technical areas until the concept/technology is adequately matured to proceed to acquisition. Figure 4 depicts this process.

Fully matured in this sense means that development of the ATD has been sufficient such that it has been demonstrated technically feasible, affordable and can be integrated into war fighting tactics, doctrine and structure. If the system meets these aforementioned criteria, <u>and is funded</u>, then it will proceed either to a new acquisition or as a technological insertion into an existing program or system.

## B. ATD INTERFACES

### 1. Simulation and Synthetic Environments

The development of simulations and synthetic environments is critical to the success of the new flexible acquisition strategy: ATDs. Currently it is very cost intensive to develop and test a weapon system. It is particularly costly to develop

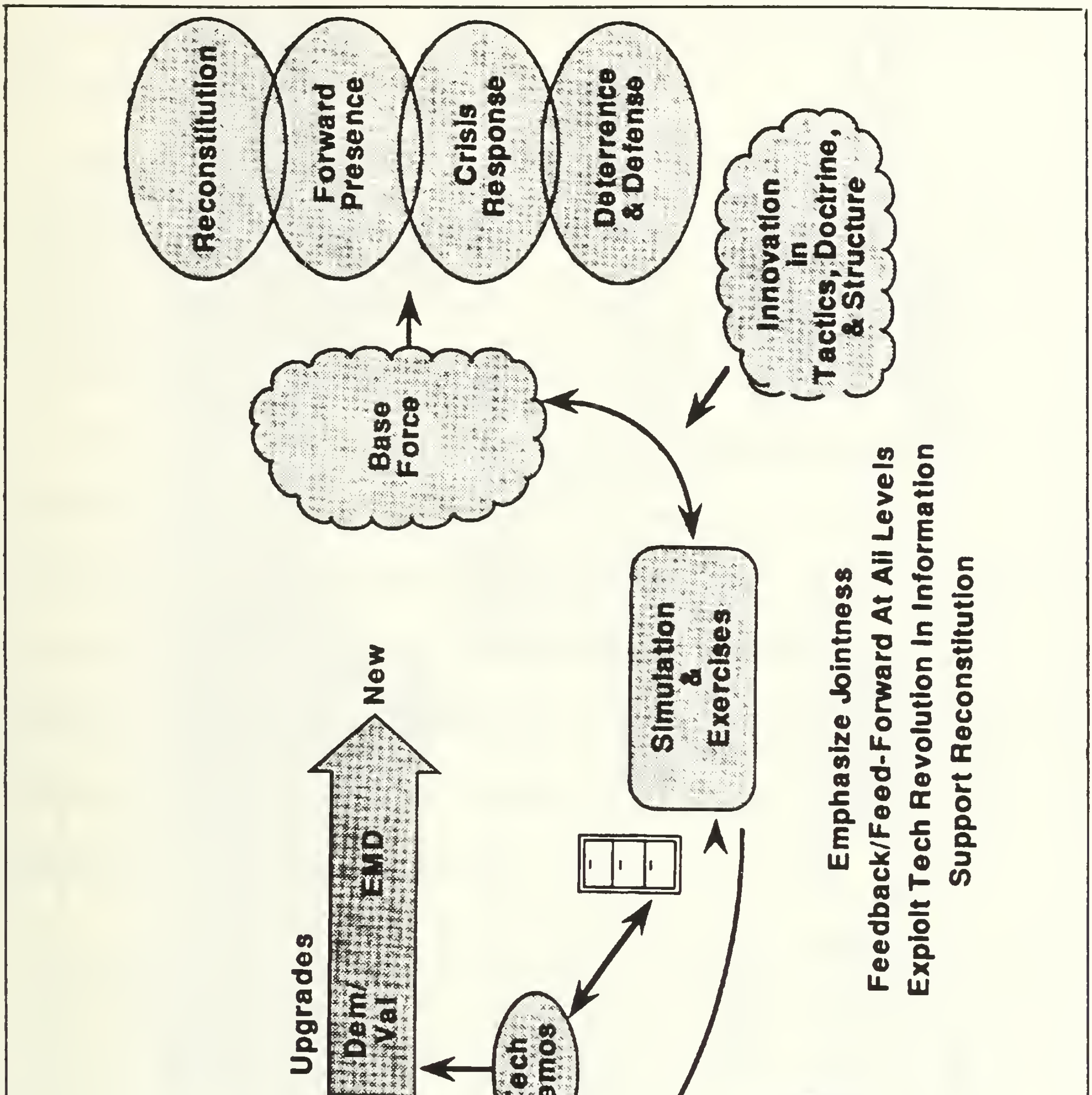


**Figure 3** The New Defense S&T Strategy: Acquisition, (from p. I-9).

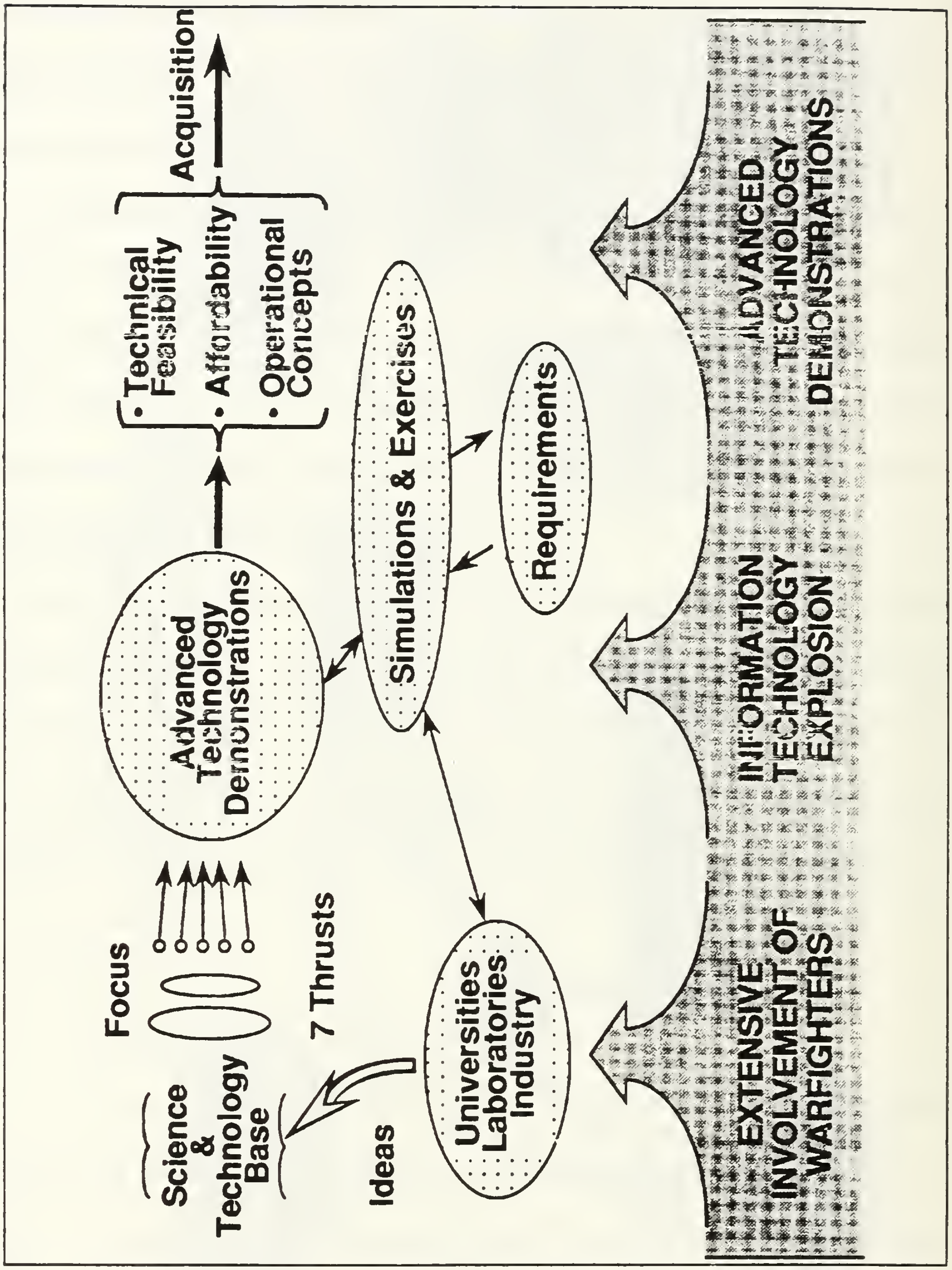


**Figure 4** ATD Transition to Acquisition (from Defense S&T Strategy, p. I-11).

complex systems that require extensive human interactions. The Defense Science and Technology Strategy establishes this as Thrust Six:

> **Synthetic Environments.** A broad range of information and human interaction technologies must be developed to synthesize present and future battlefields. We therefore must synthesize factory-to-battlefield environments with a mix of real and simulated objects and make them accessible from widely dispersed locations. Integrated teams of users, developers, and/or testers will be able to interact effectively. Synthetic environments will prepare our leaders and forces for war and will go with them to the real battlefield.[39]

An excellent example of this research technology is the NPSNET at the Naval Postgraduate School. "The goal of the project has been to create a low-cost, Government owned, workstation based visual simulator that utilizes SIMNET [Simulation Network] databases and SIMNET and DIS [Distributive Interactive Simulation standard] networking formats."[40] NPSNET is also considered a "virtual world system." The following is a detailed definition of "virtual world systems," particularly as they pertain to NPSNET:

> . . . any system that allows the user to interact with a three-dimensional computer-graphics generated environment. There are two kinds of virtual environment: a simulation of a real environment that may be too expensive, too dangerous or too frivolous to interact with in the 'real world' (virtual reality), and a totally artificial environment created for specialized applications (cyberspace). As NPSNET stands currently, it is a virtual world, created to explore and interact with 3D terrain, structures and players on that terrain.[41]

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[39] DDRE, *Defense Science and Technology Strategy*, p. ES-3, July 1992.

[40] Michael J. Zyda, David R. Pratt and Kristen M. Kelleher, *1992 NPSNET Research Group Overview*, p. 1, Naval Postgraduate School, 1992.

[41] Ibid., p. 2.

As the authors point out in their overview, the "image conjured by the phrase 'virtual reality' is that of frivolous applications of expensive gear." However, this approach also serves as a relatively inexpensive and safe testing and research environment that will continue to play an increasing role in the development of ATDs. OSD hopes that use of this research approach will "lead to comprehensive assessments of technical feasibility, affordability, and operational utility."[42] However we must be careful not to place too much immediate confidence in this approach.

The US Army is expending considerable effort in this area: One such example is the *Louisiana Maneuvers*, scheduled for 1993 to 1997. This project has tremendous potential benefit in bringing safe inexpensive training to the force while integrating users with developers, scientists and engineers. The 1992 NPSNET Research Group Overview points out in its conclusion that, "Despite promises by the media, virtual worlds are still in their infancy, and there is no assurance that the technology will develop as quickly as publicists claim." Therefore, we must cautiously place our trust and confidence in this technology as a medium for reducing R&D risks.

**2. Introducing Virtual Prototyping**

The critical lash-up between Synthetic Environments (SE) and ATDs is in the technological capability and potential to synthetically prototype a given system,

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[42] DDRE, *Defense Science and Technology Strategy*, p. ES-2, July 1992.

with variants and changes. Virtual Prototyping offers very useful benefits in implementing the use of ATDs:

> The attributes and impacts of systems will be rapidly changed and studied on the [electronic] battlefield. Virtual prototypes will be produced, and design and manufacturing tradeoffs evaluated. The first manufactured unit will be the 'B Model,' incorporating lessons learned on the synthetic manufacture of a synthetic A Model.[43]

One of the greatest potential savings in this area is in terms of both cost and schedule. User (operational) Testing of critical sub-systems and components is an immediate application of SE in "virtual prototyping." Before the availability of SE, sub-system/component design could only be tested and refined by bread boarding, brass boarding, incorporation into existing analogous systems, or (worst case) after developing the system prototype. Virtual Prototyping provides a cost effective and timely approach to the Test-Analyze-Fix-Test (TAFT) approach to systems development.

For example, virtual prototyping could be used to get operator feedback on a new (hypothetical) "heads up" gunner's display design. The operating characteristics and parameters of the display, as well as the overall system, could be input to a synthetic environment. Using a head mounted (virtual) display and the system's proposed or existing interface hardware configuration, a gunner could use the "heads up" display in a realistic, mission oriented environment. (This concept was

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[43] Ibid., p. II-56.

developed by and has been used for many years in the aviation community.) During the course of this virtual prototype testing, data and feedback can be collected, resulting in acceptance or revision of the original design. The real benefit is the savings in the time and cost of physical prototyping and testing on physical ranges and environments.[44]

Mr. Robert A. Warren, Professor of Engineering Management at the Defense Systems Management College (DSMC) stated in a telephone interview on October 15, 1992:

> We've got to find a way of using this [simulation] capability to ensure that operating concepts are understood before the [production] transition occurs. The way the SIMNET works is that the scientists, engineers, developers, manufacturers and warfighters will use it [SIMNET] as a common communication vehicle. In other words, if you try to get scientists to talk to war fighters without some sort of a translator, you have the rough equivalent of a 'Tower of Babel.' Therefore, the Science and Technology Strategy has a very heavy emphasis on synthetic environments, which are electronic battle fields. These will enable early and continuous involvement of the user with the scientists, engineers, developers and manufacturers.

### 3. Virtual Prototyping at the US Army Tank Automotive Command

The Advanced Systems Concepts Division of the Tank Automotive Research, Development and Engineering Center (TARDEC) in Warren, Michigan

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[44] This idea is based on a conversation with Mr. Robert A. Warren, Professor of Engineering Management, Defense Systems Management College (DSMC), October 15, 1992. It is also based on previous experiments with NPSNET and other SIMNET applications in DOD.

has been working diligently on this concept in recent years. Figure 5 is a comparison between the traditional approach to development and the new (virtual) approach.

Traditionally, each step in the design process requires an iterative change process (loops). This is a very costly and time consuming process. Using virtual prototyping significantly reduces or eliminates the need to physically change prototypes. Simulation of virtual prototypes allows a "concurrent everything" approach to system development. The simulation, as the "common communication vehicle", allows all the key players involved in the development to work their respective areas concurrently. The result is integrated, optimal design at a reduced cost in less time.

Another significant benefit of bringing all the key players "on-line" is related to the development of realistic, attainable system requirements and specifications. Simulating virtual prototypes allows the free participation and communication of the user with the developer. This allows the user to communicate operational requirements consistent with developer design and production capabilities. If a critical operational requirement drives an advanced technological design, then the developer has much more lead time to devote to development of associated manufacturing processes.

For those ATDs meeting the criteria to proceed to acquisition (on page 30), virtual prototyping offers a significant potential improvement in the total time required to develop a new weapon system. Figure 6 is a comparison of the typical

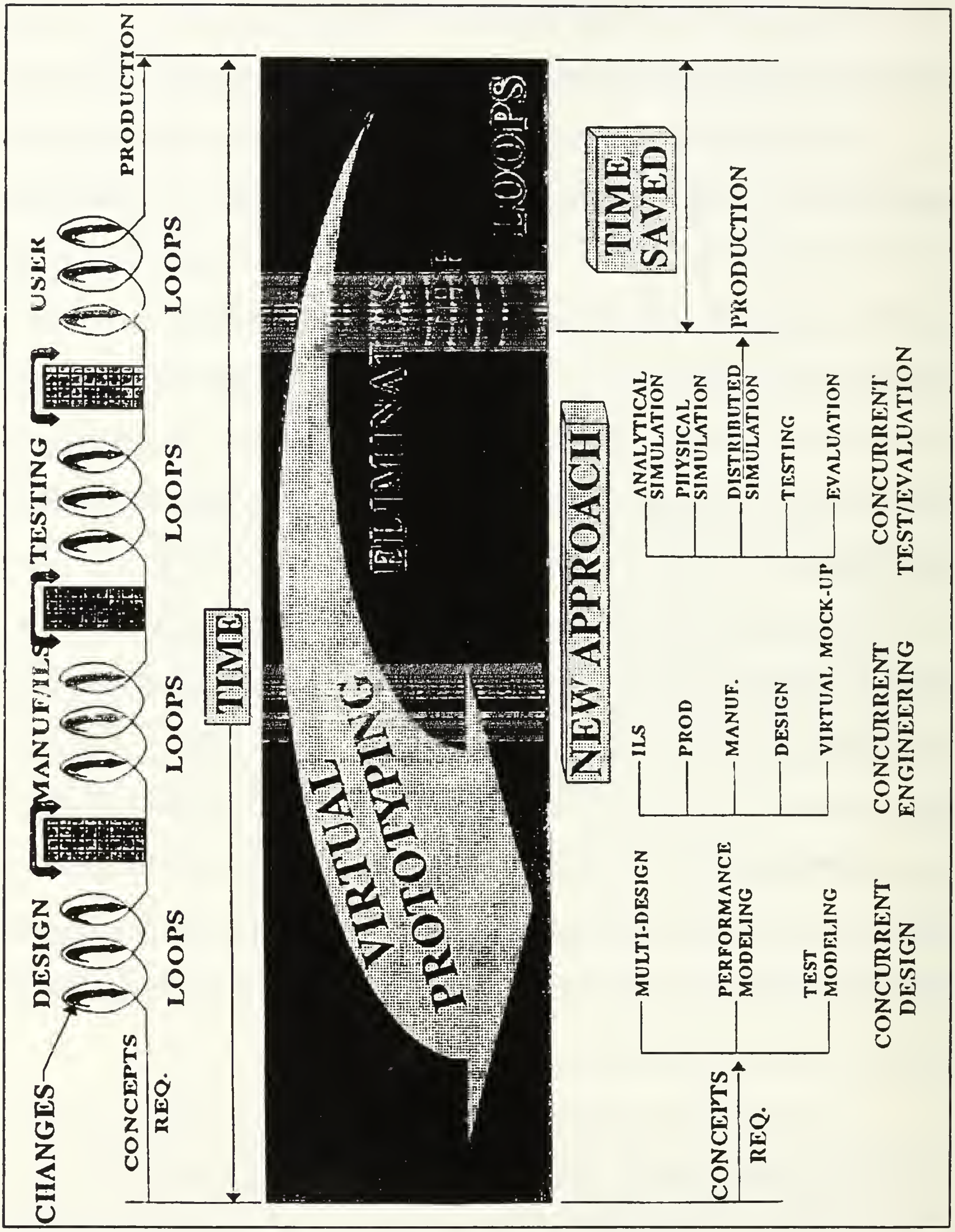

**Figure 5** Impact of Virtual Prototyping (TARDEC graphic).

(traditional) development process compared to the possible improvements using virtual prototyping.

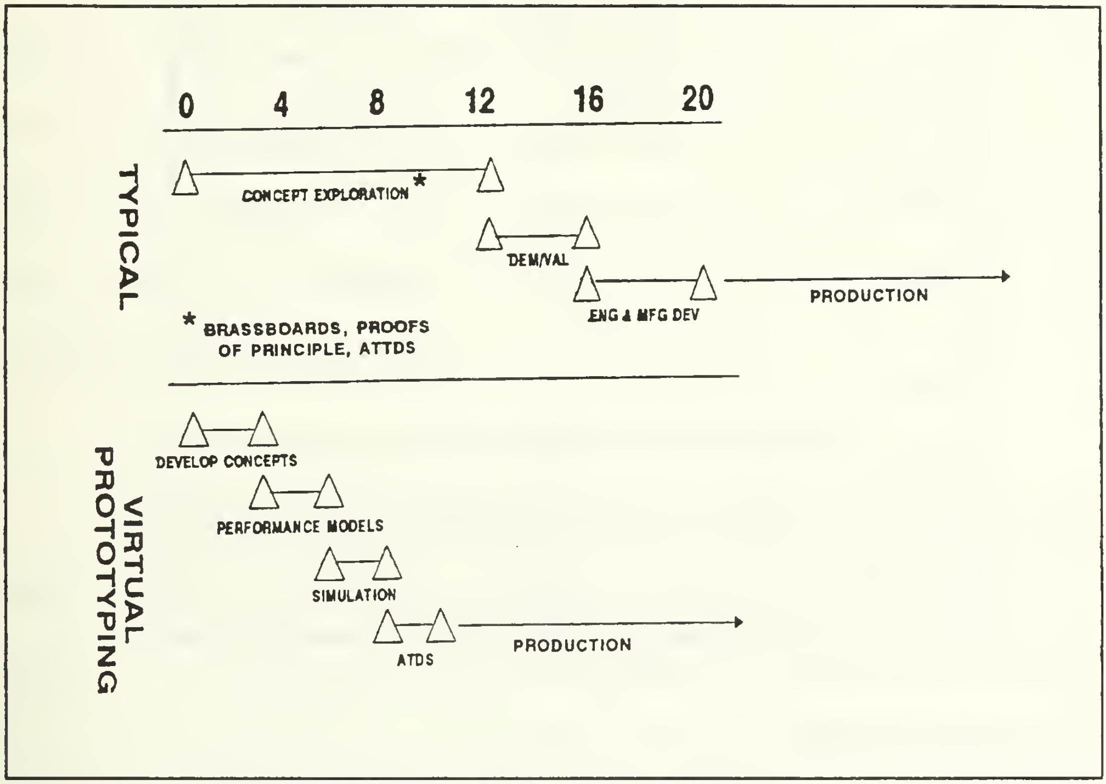


**Figure 6** Typical Development Process vs. Virtual Prototyping (TARDEC graphic)

The potential improvement in the length of the acquisition process alone seems to justify the use of virtual prototyping in the ATD process. J. Ronald Fox, in his book, *The Defense Management Challenge: Weapons Acquisition*, looked at nine weapon system programs. Seven unclassified development times, of the nine he examined, follow:

| SYSTEM | TOTAL YEARS |
|---|---|
| Phalanx | 15+ |
| Sea Launch Cruise Missile | 12+ |
| Captor | 18 |
| Patriot | 19.5+ |
| Stinger | 13 |
| A-10 | 11+ |
| EF-111A | 17+ |

Fox points out that:

The lengthy acquisition process (seven to ten years, or longer) for major weapon systems is a central problem, and produces other acquisition problems. The 1986 Packard Commission pointed out three typical hazards.

- It leads to unnecessarily high costs of development. Time is money, and experience argues that a ten-year acquisition cycle is clearly more expensive than a five-year cycle.

- It leads to obsolete technology at the time of deployment.

- It aggravates the concern that is one of its causes. Users, knowing that the equipment designed to meet their requirements is fifteen years away, make extremely conservative (i.e., high) threat estimates. Because long-term

forecasts are uncertain at best, users tend to err on the side of overstating the threat.[45]

Virtual prototyping will significantly reduce these tendencies by "concurrent everything", and continual user interaction with the developer, scientists, engineers and manufacturer. Experience has shown that "time is [indeed] money." DOD and the Services must make every effort to maximize the use of virtual prototyping in the iterative design process. Virtual prototyping has the potential to significantly reduce cost, schedule and production risk.

#### 4. CAD as the First Step Toward Virtual Producibility

TARDEC Advanced Systems Concepts Division uses three dimensional Computer Aided Design (CAD) workstations to input the system design into the simulation. This 3-D design enables solid modeling of the system in the simulation. Design improvements can be easily produced and analyzed using Computer Aided Engineering (CAE) capabilities. Improved designs are therefore easily introduced into the next run of the simulation. The loop is therefore completed at less cost than physical prototyping and in less time.

CAD systems are usually associated with the term CAD/CAM (Computer Aided Manufacturing). As they are most frequently used, the term CAD is more

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[45] J. Ronald Fox with James L. Field, *The Defense Management Challenge: Weapons Acquisition*, pp. 28 - 29, Harvard Business School Press, Boston, Massachusetts, 1988.

appropriate since it is normally used primarily in a design and modeling function. However, the CAM function is critical to CIM (Computer Integrated Manufacturing) capability. Assuming that the ultimate objective of the virtual prototype, through ATD, is production and deployment, using CAD in this role provides a vital link to ultimate manufacturability of the system. CAD is the entry vehicle of the design into the world of computer integration.

Volume V of the Tool and Manufacturing Engineers' Handbook (TMEH), *Manufacturing Management*, states that:

> Computer-aided design (CAD) is the principal technology that begins a product design cycle. Computer-aided design actually comprises a number of technologies involved in the creation and analysis of a design - whether that design is a three-dimensional part to be machined, a printed circuit board, or a plant layout. In the CIM environment, the design data generated on the CAD system is used by other CIM technologies in the manufacture of the product.
>
> Once largely used as a drafting tool, CAD has become a pivotal technology for those who use it properly. The design data generated on the CAD system interacts with numerous other automation systems in a modern manufacturing company. And the part geometry captured in the system's engineering database can be used to design the physical work environment in which that part will be produced, including fixturing, tooling, and transportation equipment. Some CAD systems can, as well, simulate the operation of the workcell that will produce the part and generate the required machine tool and robotic programming.
>
> Computer-aided design equipment allows a designer to create images of parts, integrated circuits, assemblies, and models of virtually anything . . . from molecules to manufacturing facilities - at a graphics workstation connected to a computer. These images become the definition of a new design, or the modification of an existing one, and are assigned geometric, mass, kinematic,

material, and other properties simply by the user interacting with the computer.[46]

Using this technology in this way allows a system design to be technically analyzed and evaluated in terms of:

- Mobility
- Dynamics
- Vulnerability
- Geometric/Weight/Mass Properties
- Statics and Strengths of Materials/Kinematics Properties
- Hydraulics/Electronics Properties
- Human Factors and Logistics Supportability
- Cost, Schedule and Risk
- Producibility

Connectivity between the user and the development/manufacturing community is perhaps the greatest gain in using a virtual prototyping approach to ATD development. In addition to the connectivity, CAD enables an efficient step in the direction of producibility. It is important to note that, although a weapon system can be virtually prototyped, and many parts easily produced as a result, this does not equate to automated production of the system. It is a strong step in the

[46] TMEH Vol. V, Fourth Ed., *Manufacturing Management*, p. 16-4, Society of Manufacturing Engineers, Dearborn, Michigan, 1983.

right direction; however, a major shift in the design, development and production paradigm is required for success.

### 5. Computer Integrated Manufacturing (CIM)

It is critical that Computer Integrated Manufacturing (CIM) be incorporated into the ATD process. The Society of Manufacturing Engineers (SME) strongly supports the use of CIM in manufacturing enterprises. In Volume V of TMEH, the following statement identifies the urgency of need in this area:

> The importance of computer-integrated manufacturing (CIM) to the future of US Manufacturing cannot be overstated. It is a key ingredient in improving the productivity, efficiency, and profitability of the US industrial base and in regaining a competitive position in the world marketplace.
>
> Computer-integrated manufacturing is the view of manufacturing that recognizes that the different steps in the development of a manufactured product are interrelated and can be accomplished more effectively and efficiently with computers. These relationships are based not simply on the physical part or product being produced but also on the data that define and direct each step in the process. Controlling, organizing, and integrating the data that drive the manufacturing process through the application of modern computer technology effectively integrates all the steps in the manufacturing process into one coherent entity. Such integration should yield efficiencies not possible from a more segmented approach to manufacturing.[47]

Adoption of CIM into acquisition policy and enterprises will require a significant paradigm shift in acquisition management. The *Handbook of Manufacturing Automation and Integration* states that CIM is a philosophy:

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[47] Ibid., p. 16-1.

CIM is the harnessing of all information required to correctly create products that comply with the business plan of the enterprise . . . . Because CIM is a philosophy, it cannot be bought.[48]

In DOD's case, the "business plan of the enterprise" equates to all of the documents regarding a given program (e.g., Operational Requirements Document, Acquisition Strategy, Acquisition Plan, Transition to Production Plan, etc.). CIM is indeed a philosophy that demands, like Total Quality Management (TQM), a genuine commitment to continuous improvement throughout an organization, from the top down. An organization cannot go out and acquire CIM. It must be concurrently nurtured and developed, from both short range and long range perspectives, one step at a time.

Not unlike TQM, translating CIM from a philosophical theory into practice demands a clear definition of the concept. The difficulty here arises from the dynamics of all of the interrelationships involved. CIM involves multiple engineering disciplines, management, budget and finance, facilities and resources, materials handling and supply, scheduling, and a myriad of other strategic concerns. All of these areas are dynamic and interdependent. The National Research Council provides the following definition:

CIM includes all activities from the perception of a need for a product; through the conception, design, and development of the product; and on through production, marketing, and support of the product in use. Every action

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[48] *The Handbook of Manufacturing Automation and Integration*, p. 18, Warren, Gorham & Lamont Inc., John Stark - Editor, 1989.

> involved in these activities uses data, whether textual, graphic, or numeric. The computer, today's prime tool for manipulating data, offers the real possibility of integrating the now often fragmented operations of manufacturing into a single, smoothly operating system. This approach is generally termed computer-integrated manufacturing.[49]

This definition gives rise to perhaps a more broad term, that encompasses DOD efforts to integrate the user, scientist, developer and manufacturer. Perhaps the term **Computer Aided Weapon Systems Acquisition (CAWSA)** might be more appropriate. Modifying the definition from above, CAWSA would include all activities from the perception of a threat, the determination of the need for a materiel solution and requirements generation; through concept exploration, simulations, virtual prototyping, virtual manufacturing, demonstration and validation or ATD, and EMD; and on through production, fielding and life cycle support of the system. "Every action involved in these activities uses data, whether textual, graphic, or numeric." "The computer, today's prime tool for manipulating data, offers the real possibility of integrating the now often fragmented process" of Research, Development and Acquisition, along with associated contracting, costs and budgeting, into a single, smoothly operating system. (The feasibility of implementing CAWSA methodology will be addressed in Chapter V.)

The Computer-Aided Acquisition and Logistics Support (CALS) program paves the way for a next generation integrated acquisition system. Interconnectivity

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[49] TMEH, Vol. V, *Manufacturing Management*, p. 16-1, SME, 1983.

is the key to future integration. Figure 7 is a graphic diagram that the Computer and Automated Systems Association of the Society of Manufacturing Engineers (CASA/SME) developed to visualize "how technologies and disciplines work together as a unified whole."[50]

"The CIM Wheel is composed of five fundamental dimensions: (1) general business management, (2) product and process definition, (3) manufacturing planning and control, (4) factory automation, and (5) information resource management."[51] A similar wheel could be developed that encompasses the many dimensions of the DOD RD&A process if integrated. Yet, there are definite obstacles to implementing CIM. According to *The Handbook of Manufacturing Automation and Integration (p. 18)*, they are:

- Lack of standards [CALS should alleviate this.]
- Insufficient commitment [top down, throughout an organization]
- Obsolete cost justification methodologies
- Insufficient Expertise
- Poorly defined goals
- Lack of decision criteria
- Lack of planning

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[50] Ibid., p. 16-2.

[51] Ibid.

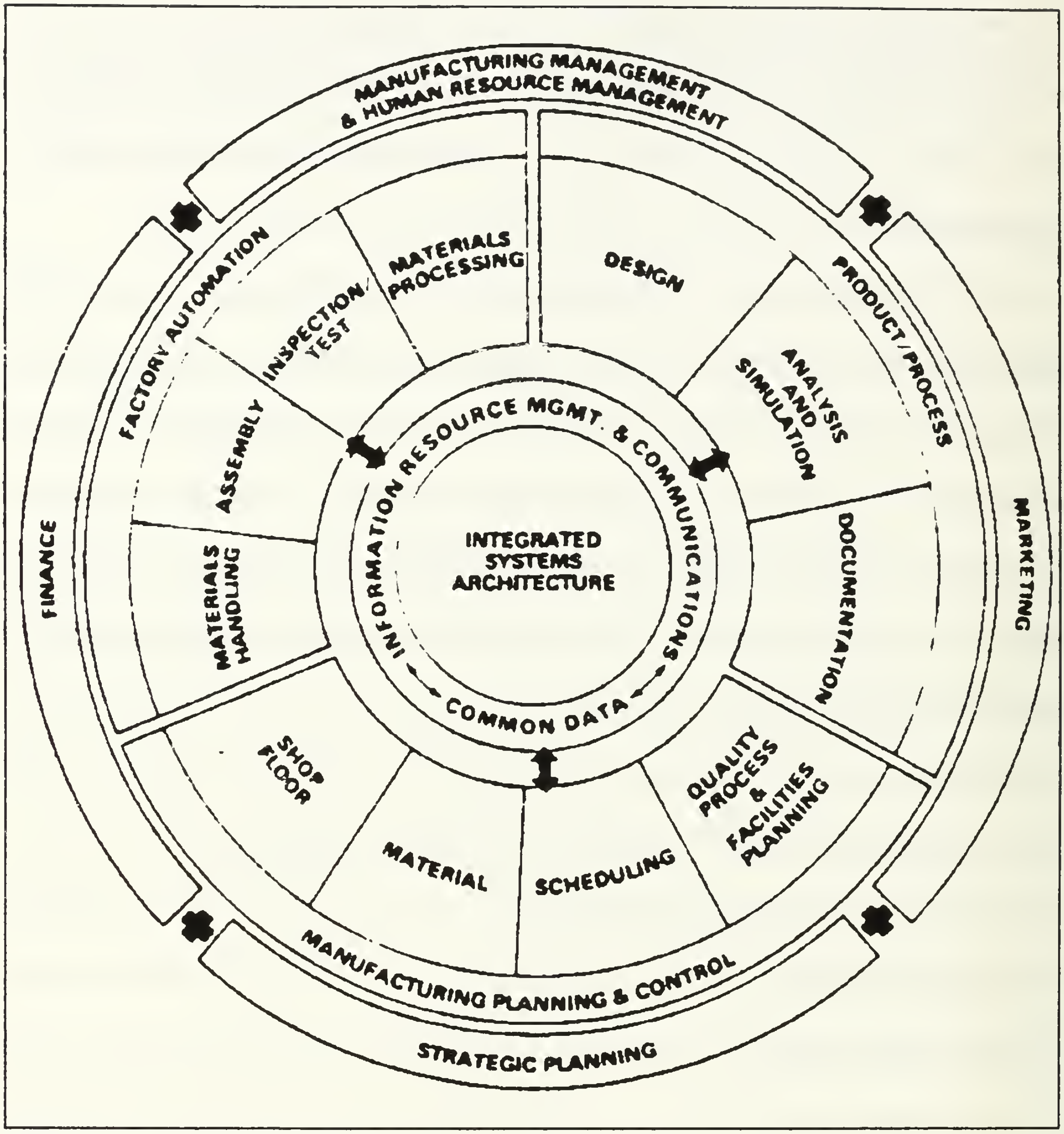


**Figure 7** The CIM Wheel (TMEH, Vol. V, p. 16-2)

These are all obstacles that DOD should be aware of, and plan to overcome in the future. Not beginning to plan for an integrated RD&A system would be a costly mistake. The suggestion here is by no means an indorsement of

a purple suit organization to accomplish RD&A; however, many of the efficiencies that such an organization portends are attainable via computer systems integration.

According to the US National Research Council:

> CIM improves production productivity by 40% to 70%, engineering productivity by a factor of 3 to 5, and quality by a factor between 2 and 5, while decreasing engineering design costs by 15% to 30% , overall lead time by 20% to 60% and WIP inventory by 30% to 60%.[52]

CIM has significant potential to reduce costs in DOD systems acquisition.

### 6. Computer Aided Process Planning (CAPP)

Computer Aided Process Planning (CAPP) is one method of overcoming the difficulty of closing the gap between CAD and CAM. Volume V of TMEH states:

> Computer-aided process planning systems are, in effect, expert systems that capture the knowledge of a specific manufacturing environment plus generic manufacturing engineering principles. This knowledge is then applied to a new part design to create the plan for the physical manufacture of the part. This plan specifies the actual machinery employed in the part production, the sequence of operations to be performed, the tooling, speed and feeds, and any other data that is required to transform the design to a finished product. To use CAPP most effectively in a CIM environment, the design should originate on a CAD system and be electronically transferred to the CAPP system from the database.[53]

Since designs and models are being developed for simulation using CAD (e.g., TARDEC systems virtual prototyping), it would be a logical step to proceed to

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[52] *Handbook of Manufacturing Automation and Integration*, p. 67, Warren, Gorham and Lamont Inc., John Stark - Editor, 1989.

[53] TMEH, Vol. V, *Manufacturing Management*, p. 16-7, SME, 1983.

CAPP. Since CAPP uses the same database as CAD, this would not be a difficult transition.

Process planning is certainly not a new concept. Manually it is very time consuming and costly. The idea behind CAPP is to take the knowledge and procedures of experienced individuals and include it in a logical, automated process. This way, when the most experienced individuals in an organization leave or retire, much of their previously used knowledge and capability can be institutionalized in the form of an expert system.

The idea then is to take that "captured knowledge and logic" and apply it to new tasks by either modifying the baseline process, or modelling it to develop a new process. In either case, expertise is a critical link in bridging the gap between CAD and CAM.

### 7. Group Technology (GT) in the CIM Environment

Group Technology (GT) is a methodology that should be considered and included up front in the design and development of any CIM effort. It is also another method that can help close the gap between CAD and CAM. TMEH Volume V describes GT as follows:

> Group technology, like CAPP, uses previous experiences in engineering and manufacturing to streamline current practices. Group technology is more accurately defined as a methodology rather than a technology. It is a method of organizing part designs and their manufacturing processes so that they can be grouped into families that have similar characteristics. GT is also a method of organizing a manufacturing facility by cells according to the types of parts

manufactured and the types of equipment used to manufacture them. It is a software-oriented rather than a hardware-oriented technology.[54]

Plainly stated, GT is a method of simplifying part designs and associated manufacturing processes to reduce redundancy in design and manufacturing effort. The logical basis for grouping parts designs is based on process. This approach provides a cohesion throughout the CIM environment for organizing data and associated processes.

Because of the efficiencies gained by simplifying parts designs and manufacturing processes, the beneficial effects are quite significant. According to SME, "it can be used to reduce the number of parts in a company's database, new part introduction costs, product design lead time, scrap, and overall design cost, and to increase effective capacity utilization." SME has observed that GT also results in:

- 52% reduction in part design.
- 10% reduction in numbers of new shop drawings through standardization.
- 60% reduction in industrial engineering time.
- 40% reduction in raw material stocks.
- 62% reduction in work-in-process inventory.[55]

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[54] Ibid., p. 16-8.

[55] Ibid.

### 8. Integrating the Factory Floor

#### *a. Distributed Numerical Control*

Distributed Numerical Control (DNC) is the concept of maintaining machine numerical control data in a common data base to control individual machines in a manufacturing center. TMEH states:

> Distributed numerical control (DNC) is the outgrowth of direct numerical control, which is the concept of linking a computer containing the part programs and associated information to the NC control attached to a machine tool. In this concept, the computer would download programs as needed. . .[56]

DNC is very effective since the numerical data are centrally maintained in a "higher level DNC computer." This allows the higher level DNC system to individually control and obtain feedback from individual workstations. Changes in design or specifications are automatically incorporated into the instructions to the CNC machines. Figure 8 depicts a typical DNC system.

It is interesting to note that if actual computer numerically controlled (CNC) machine tools were replaced by simulated machines, the concept of "virtual manufacturing" would come a step closer to reality. However, simulating the manufacture of parts is significantly less complicated than simulating assembly, especially human assembly, of components, subsystems and systems.

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[56] Ibid., p. 16-13.

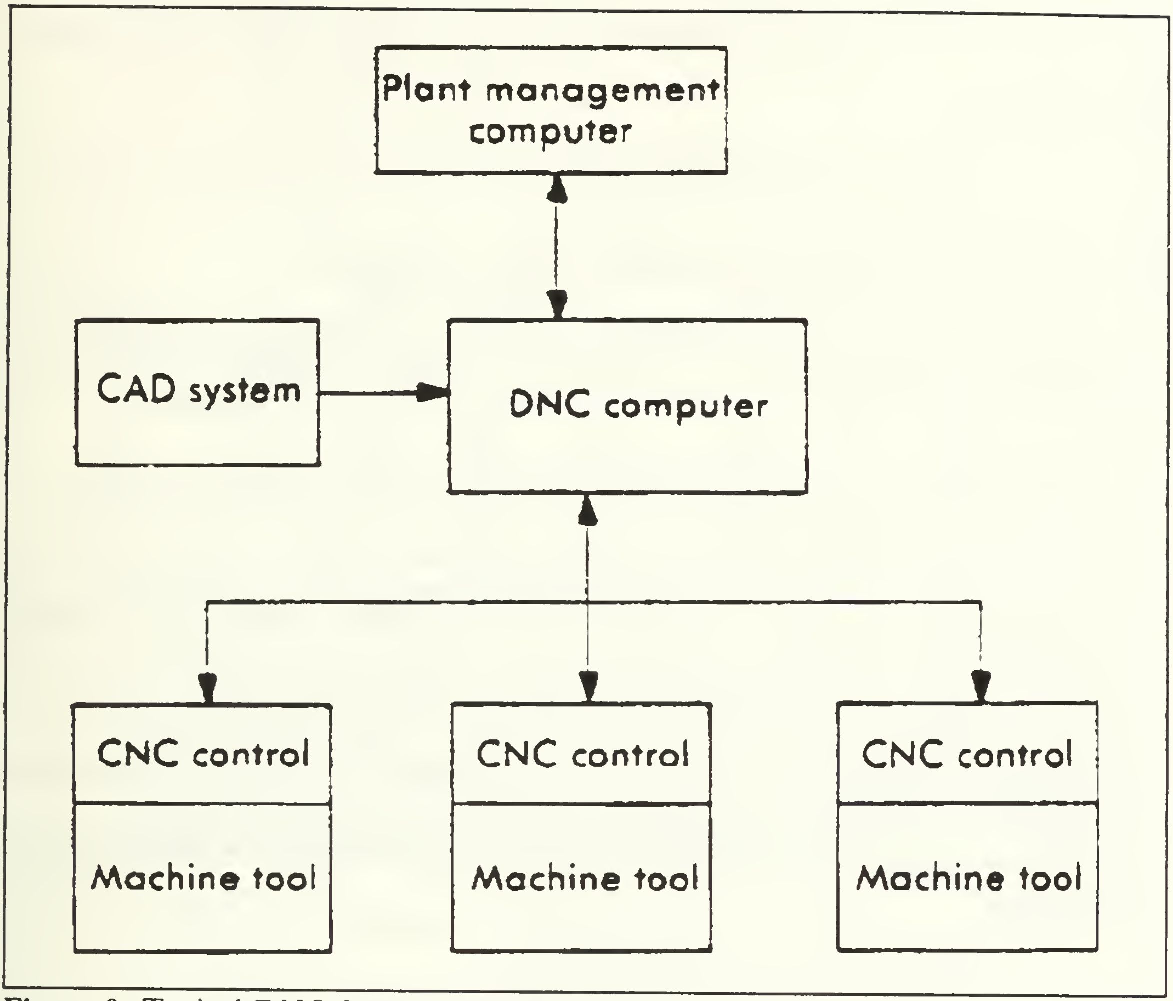


**Figure 8** Typical DNC System (TMEH, Vol. V, p. 16-13).

*b. Manufacturing Cells and Flexible Manufacturing Systems (FMS)*

The Defense Science and Technology Strategy places a great deal of emphasis on Flexible Manufacturing Systems (FMS) to achieve affordability objectives. The idea espoused is to use FMS to "decouple cost from volume."[57]

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[57] DDRE, *Defense Science and Technology Strategy*, p. ES-4, July 1992.

Analyzing the ATD concept, one can see the apparent need to reduce low-volume production costs.

There is very little distinction today between manufacturing cells and FMS. SME had the following to say regarding manufacturing cells:

> Manufacturing cells are considered by many to be the most important manufacturing advance of this decade [the 80s], particularly for batch manufacturing. The cell is, actually, a basic concept of group technology.
>
> The definition of a manufacturing cell and its use in the CIM environment has been affected by trends in the related technology of flexible manufacturing systems. When FMS technology was first introduced, systems were large and complex, often containing special customized machinery. More recently, manufacturing companies, looking for the benefits of FMS without an enormous initial investment (approximately $10 million - $20 million), have opted to begin an investment in FMS with a small, cell-like system using standard machinery and then grow it into a larger FMS configuration. This development blurs the distinction between cell and system technology into one of semantics. Whatever formal definitions are used, manufacturing cells and manufacturing systems have become the cornerstone of modern manufacturing technology.[58]

SME went on to describe FMS:

> . . . like manufacturing cells, are groups of computer-controlled machine tools linked by an automated material handling system, controlled by a common supervisory computer control, and capable of processing parts in random order. Variations in the parts handled are accommodated by the FMS machinery directed by the supervisory control.[59]

Examples of a typical FMS and flexible assembly system are shown at Figure 9 and Figure 10 respectively.

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[58] TMEH, Vol. V, *Manufacturing Management*, p. 16-9, SME, 1983.

[59] Ibid.

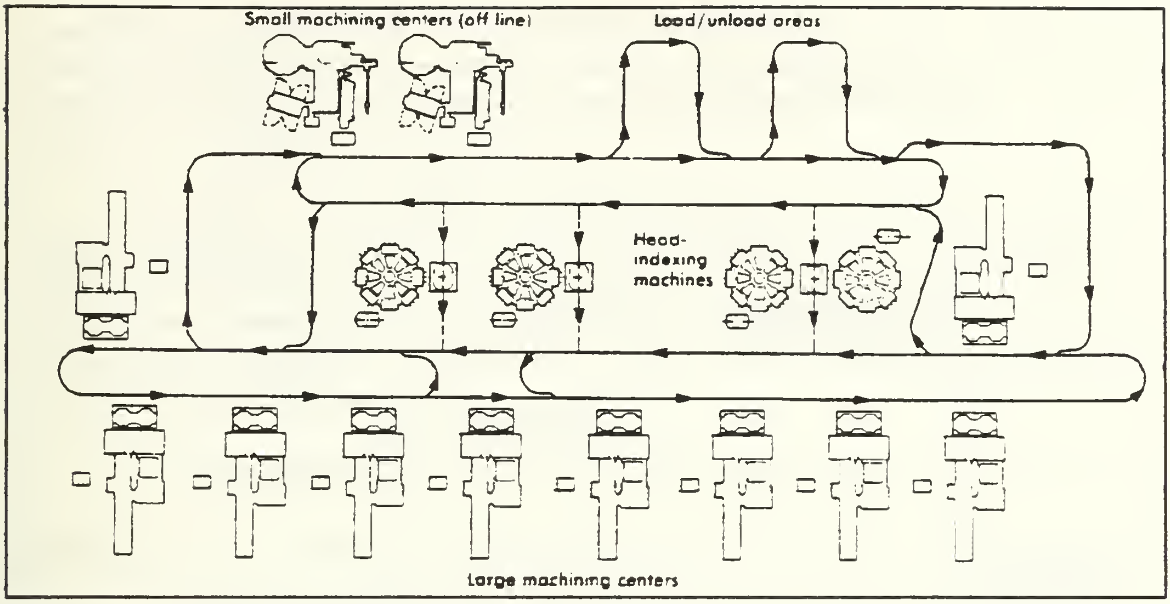

**Figure 9** Typical FMS (TMEH, Vol. V, p. 16-9).

FMS lends itself easily to simulation to evaluate the flow of various product mixes through the system. Today, great strides are being made in developing FMS for assembly (as opposed to the typical machining type operations). Modularity of cells is enabling this capability. As described in the definition of manufacturing cells above, modularity allows an enterprise to invest in flexible manufacturing capability a "piece" at a time. The real enhancement in flexible assembly resides in the intelligence of the controller.[60]

The Report to Congress on the Development of a National Defense Manufacturing Technology Plan (NDMTP), dated March 1992, states:

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[60] Manufacturing Engineering Magazine, *Cells Get It Together*, pp. 45 - 47, June 1992.

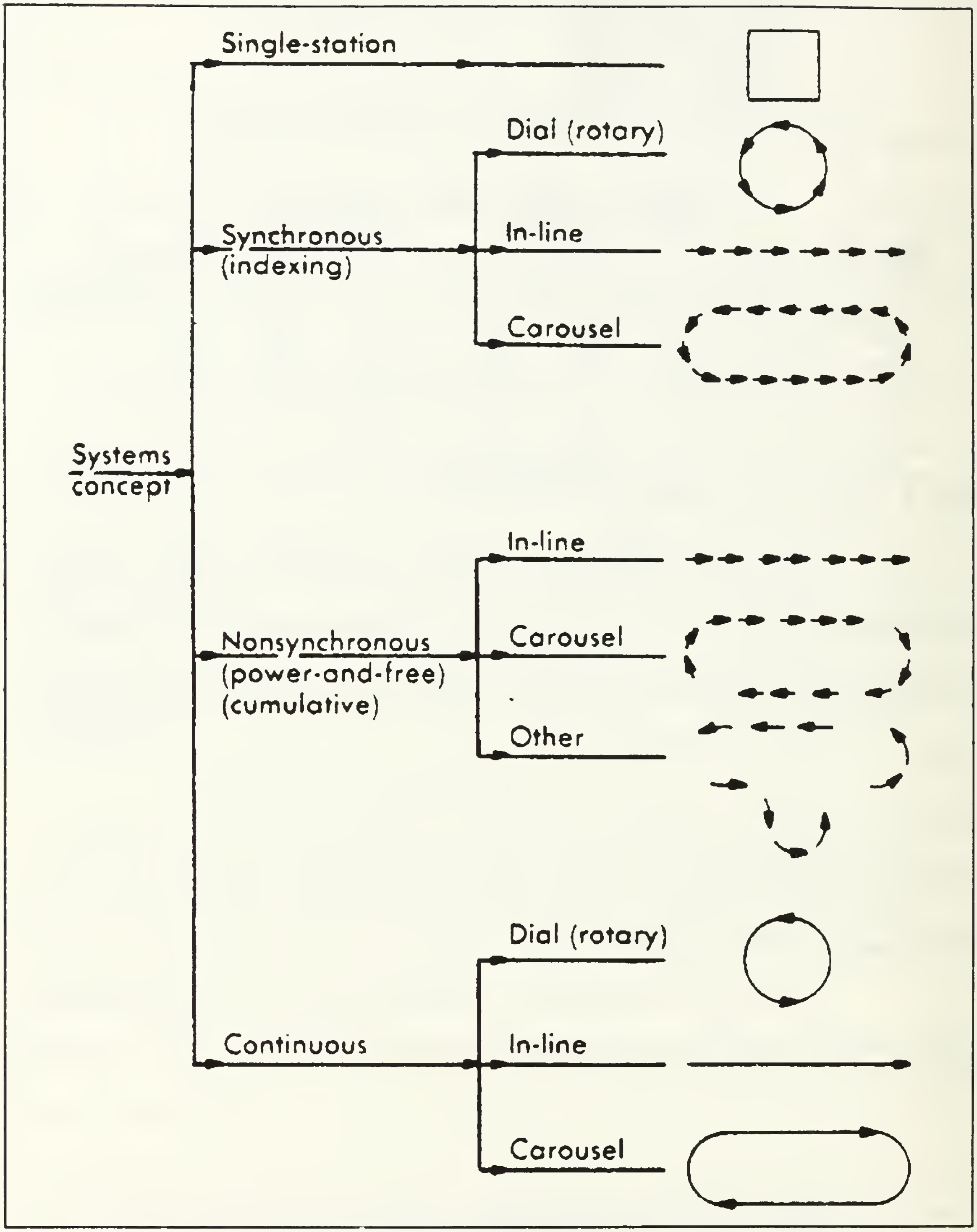


**Figure 10** Typical Flexible Assembly System (TMEH, Vol. V, p. 16-10).

> **Flexible Manufacturing will increase responsiveness.** As a result of increased global competition and consumer preference for variety, companies are adopting flexible manufacturing systems that are enabling them to respond quickly to individual requirements. . . .
>
> *The implication for defense:* Implementing flexible manufacturing systems (FMS) within the defense base may help meet DOD's requirements for speed, agility and resourcefulness. In addition, FMS will enable commercial industry to switch to defense production quickly. These flexible systems will also enable commercial industry to manufacture a wide range of products with little additional capital investment.[61]

While FMS provides all of the benefits espoused above, there is one significant fallacy. FMS requires significantly more than "little additional capital investment." FMS systems typically cost in the range from $10 million to $20 million. Most Defense Contractors, and especially lower tier manufacturers, do not have that kind of capital to invest. The most common approach, as indicated in text above, is that a manufacturer invests in manufacturing cells which can be "grown" into FMS systems eventually.

There are Government owned FMS systems in contractor plants already, that are not being utilized anywhere near capacity. The former General Dynamics plant in Pomona, California that manufactured the Navy's "Standard" missile, had Government owned FMS that were very under-utilized. Perhaps a detailed analysis of DOD FMS utilization would significantly enhance Government capital efficiency. Chapter V provides a detailed analysis of this issue.

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[61] *Report to Congress on the Development of a National Defense Manufacturing Technology Plan*, pp. 7 - 8, DOD P&L, March 1992.

The NDMTP also cites IBM's Research Triangle Park, North Carolina, facility's flexible manufacturing system. Although IBM has been quite successful in manufacturing up to 54 different models of PS computers in any order, standard components plays a vital role in such a system. This success does not necessarily bode the success of FMS in similar ATD applications.

c. *Agile Manufacturing.*

One step beyond FMS takes one into the realm of "Agile Manufacturing." Modularity of manufacturing cells and FMS makes it feasible to provide total factory floor agility. The CIM concept makes it possible to integrate all of these capabilities. Given increased emphasis on Flexible Assembly Systems, and FMS in advanced technologies like composites, avionics, and optical interfaces, true "agile manufacturing" may be realizable in the near term. Whether or not it will be readily affordable to the commercial sector for common applications is another issue altogether.

NDMTP goes on to say:

> **Manufacturing agility will improve competitiveness.** To succeed in a global market, the Japanese are attempting to reduce tooling and equipment conversion time by one order of magnitude within ten years. American companies must match this capability to remain competitive. Many companies are using design for assembly software to improve the manufacturability of their products.
>
> Example: The Engineering and Manufacturing Group of NCR Corp. used Boothroyd Dewhurst Inc.'s Design for Manufacture and Assembly software to develop a printer that uses 80% fewer parts and can be assembled in 63% less

time. This has enabled NCR to reduce time to market, and as a result, increase its competitive position. . . .

*The implication for defense:* Utilizing design for assembly and manufacturing software and other agile manufacturing techniques will improve the ability of both commercial and the defense industrial manufacturers to satisfy DOD requirements for fast turn-around and reduced costs. As a result, companies will be able to manufacture small quantities of custom items at the low unit-costs associated with mass production.[62]

The last statement above is not necessarily true as applied to ATD production costs. Generating numerical control (NC) data on CAD/CAM/CAE systems is still expensive and time consuming. When a company is manufacturing multiple models, in various configurations, in various sequences repeatedly, the initial cost of NC data is actually being distributed over a large number of items. The overhead and engineering costs will be significantly higher for ATD production than the last statement in the quotation above leads one to believe. (Note: Design for Manufacturability is discussed in detail in Chapter IV).

NDMTP states, regarding the "characteristics of future manufacturing systems":

***Manufacturing Agility*** — The production systems of the future will not only be flexible, they will be modular and reconfigurable. As a result, they will be able to accommodate and integrate revolutionary changes in products, materials, and performance. In fact, the hallmark of the future will be the ease and speed with which new products are designed and released into the field or, in commercial terms, the market.

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[62] Ibid.

*Concurrency* — To promote efficiency, concurrent engineering will evolve to "concurrent everything." By integrating all the steps of manufacturing, including material characterization, engineering design and manufacturing processing, companies will be able to respond faster to DOD requirements.[63]

### 9. Rapid Prototyping (RP)

Rapid Prototyping (RP) is perhaps the most rapidly growing area in R&D in industry today. In the past five years this technology has grown exponentially. "CAD designs are now converted overnight into a form of plastic reality more useful than anything solids modeling can yet create and display on a flat 2-D screen."[64]

Essentially, the most valuable aspect of this technology is the ability to use CAD NC data to rapidly build a prototype out of a myriad of materials, including (but not limited to) polymers, wax, resin, paper and wood. This allows hands on examination of Form-Fit-Function and other aspects of the design.

The cost of the equipment is still rather high, starting at approximately $250,000 or more. However, great strides are also being made in developing true desk-top RP machines that interface directly with dispersed CAD work stations.

Long range, there are other capabilities on the horizon. "As NC machining continuously improves, why not just machine a prototype out of a metal block in the time it takes to build it up in plastic?" Apparently, set-up and

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[63] Ibid., p. 18.

[64] Manufacturing Engineering Magazine, *Rapid Prototyping: Beyond the Wet Look*, pp. 58 - 64, November 1992.

programming for six-sided machining is significantly greater at this time.[65] This technology may some day be useful in the manufacture of composites using processes like pultrusion and polymer/polymer matrices.

However, one must be careful not to misunderstand the scope of RP capability. There is currently no capability to use RP to produce physical models of any greater complexity than components. RP production of systems and complex sub-systems are not yet possible given current technology.

## C. THE AFFORDABILITY APPROACH TO ATDs: THRUST 7

Thrust 7, Technology for Affordability was established by the Deputy Secretary of Defense in a memorandum dated December 19, 1991, entitled *Strategic Framework for Defense Science and Technology* (see Chapter II).

> The DDR&E established 7 panels to address these 7 thrust areas. The scope of Thrust Panel 7 was taken from the Framework to include those aspects of hardware and software system-life-cycle affordability for which technology leverage exists. The program span includes 6.1 - 6.3a and ManTech [funding categories]. The Panel's product is a set of high-level strategic plans, "road maps", to guide future investments in technology for affordability.[66]

The primary objective is to develop "a new mode of defense design and production, from concept to field, that can be applied broadly to all defense systems."

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[65] Ibid.

[66] DDR&E Thrust Panel 7, *Technology for Affordability: Road Maps and Recommendations*, p.2, March 1992.

DDR&E Thrust Panel 7 established the following means as priorities in meeting technology for affordability objectives:

- Concurrent engineering which integrates the design of products and processes will be the norm.

- Flexible factory floor systems will make low-volume production and rapid evolution of critical products affordable and efficient.

- Enterprise-wide information systems will reduce overhead costs systemically.

- Integrated environments will be routinely used for the development and evolution of critical hardware-software subsystems.[67]

Thrust Panel 7 emphasized investments in "two key areas":

- Computer-aided technologies for engineering and manufacturing.

- Technologies to reduce the costs and errors involved in developing and maintaining military software.[68]

These key objectives and areas have tremendous potential for gains in manufacturing (affordability) efficiencies. In fact, much work has already been done in these areas by worldwide industry. Many of the tools addressed in the previous section (ATD Interfaces) fall clearly into these categories.

The main idea is to develop those manufacturing oriented technologies that will help to enable Thrusts 1 through 5. Figure 11 depicts this approach.

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[67] Ibid., p.4.

[68] Ibid.

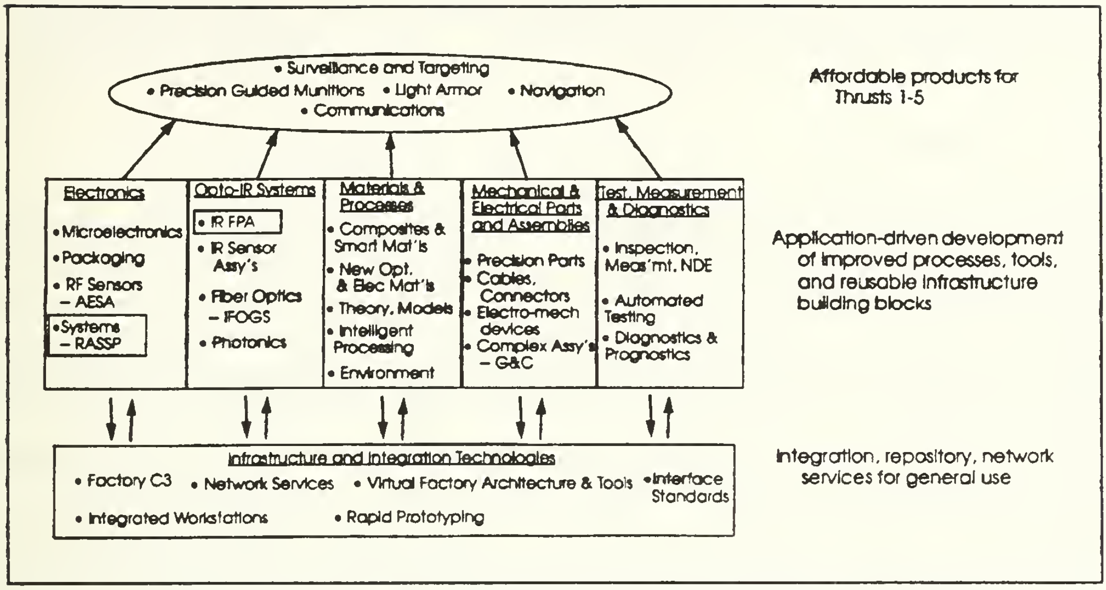


**Figure 11** Engineering and Manufacturing Demonstrations (Technology for Affordability, p. 23).

One of the most interesting, and perhaps beneficial, aspects of this approach is the "Infrastructure and Integration Technologies." Thrusts 1 through 5 tend to focus more on development of operational concepts and concurrent manufacturing process development. Under the realm of integration technologies, Thrust Panel 7 proposed the development of an "Assembly Driven Product Design/Virtual Factory."[69]

The idea of developing a "virtual factory" holds great promise for development of ATD processes. CAD, CAM, CAE, GT, CAPP, manufacturing cells, FMS and CIM all lend themselves to the success of this concept. The distinction between a "virtual factory" floor and a real factory floor becomes insignificant with CIM

[69] Ibid., p. 43.

database capabilities. Virtual factories may potentially reduce risks associated with the actual manufacturability of ATDs.

The NDMTP states:

> *Cooperative Strategies* — The integration of information within companies, between companies, and between government agencies and their suppliers will make it easier to send data around the globe than it is to make international telephone calls now. This ability to communicate will enable the formation of "virtual companies" — temporary organizations created to meet a specific need. Virtual companies are essentially "factories without walls", and consist of different organizations contributing resources to achieve a common goal. Once that goal is met, the virtual company will disband and the participating organizations will go their own ways. In addition, corporations will share production capabilities and facilities, and form joint ventures at the operational level. For example, a foreman of material removal may use the capacity and knowhow of other firms to meet his quota for the week. These cooperative strategies will help both defense and industrial corporations meet DOD requirements quickly, efficiently, and cost-effectively.[70]

This concept has significant promise. A detailed proposal utilizing the concept of a "virtual company" is presented in Chapter V of this thesis.

The new Defense Science and Technology Strategy takes advantage of the rapid advances occurring in information and manufacturing technology and management practices. These technologies have been proven effective in industry. The Naval *Best Practices* manual states:

> The annual rate of productivity improvement in the United States recently has been lower than any other major industrial country of the Western World. This can be attributed largely to the fact that our manufacturing plants are operating with tools and processes that have not kept pace with emerging

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[70] *Report to Congress on the Development of a National Defense Manufacturing Technology Plan*, p. 18, March 1992.

technology. Contractors using Computer-Aided Manufacturing (CAM) integrated with Computer-Aided Design (CAD) are experiencing phenomenal productivity increases.[71]

In addition to optimizing the use of advanced technologies, DOD must also adopt design methodologies that enable and enhance such potential capabilities. Without "state of the art" methodologies to enable and enhance "state of the art" technologies, the new Defense S&T Strategy would be relegated to an ineffective, expensive "science fair."

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[71] Department of the Navy, *Best Practices: How to Avoid Surprises in the World's Most Complicated Technical Process — The Transition from Development to Production*, p. 6-45, NAVSO P-6071, March 1986.

## IV. DESIGN FOR MANUFACTURABILITY (DFM)

### A. INTRODUCTION TO DFM

**DFM** is defined by the Society of Manufacturing Engineers (SME) as, "the practice of designing products with manufacturing in mind, so they can be designed in the least time with the least development cost," while helping to ensure a quick and smooth transition to production. DFM minimizes the cost and amount of time required to manufacture, assemble and test a product, while achieving "desired levels of quality and reliability." "Design for manufacturability is a methodology that simultaneously considers all of the design goals and constraints for products that will be manufactured."[72]

Considering the effects of current and future fiscal constraints on RD&A budgets, DFM can be incorporated to gain significant cost effective benefits. DFM is a methodology that should be included at the outset of the development of an ATD. Considering the ultimate objective of proceeding to production and deployment, it makes good business sense to consider manufacturing issues as early as possible in the development of any system. The Navy *Best Practices* manual states:

[72] TMEH, Volume VI, *Design For Manufacturability,* p. 1-1, SME, January, 1992.

Besides the more obvious performance and reliability requirements, there is the additonal demand of producibility: it must be economically feasible to manufacture a quality product at a specified rate and to deliver end items capable of achieving the performance and reliability inherent in the design. This design requirement is not always well understood and historically has taken a back seat to the more popular objective of high performance. The results of this neglect have ranged from factory rework rates in excess of 50 percent to suspension of government acceptance of end items pending major redesign and producibility. A strong producibility emphasis early in design will minimize the time and cost required for successful transition to production.[73]

It is critical to ensure that manufacturing personnel are included in the design process. The *Best Practices* manual emphasizes that manufacturing engineers must be involved early in the design process, as part of the design team, in order to ensure a manufacturable design.[74]

Including DFM early in ATD development has the potential to shorten system development time and minimize overall development costs. Helping to ensure a smooth and efficient transition to production, is an essential consideration in any ATD.

TMEH Volume VI, *Design For Manufacturability*, explains:

Many costs are reduced, since products can be quickly assembled from fewer parts. Thus, products are easier to build and assemble, in less time, with better quality. Parts are designed for ease of fabrication and commonality with other designs. DFM encourages standardization of parts, maximum use of purchased parts, modular design and standard design features. Designers will save time

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[73] The Department of the Navy, *Best Practices: How to Avoid Surprises in the World's Most Complicated Technical Process — The Transition from Development to Production*, NAVSO P-6071, March 1986, p. 4-11.

[74] Ibid.

and money by not having to 'reinvent the wheel.' The result is a broader product line that is responsive to customer needs.[75]

It is important to note that DFM was developed with the commercial enterprise in mind. Companies are primarily motivated by increased profits. Reducing product development and production costs is a very effective means of increasing profits. The speed in which a new product is introduced into a given market also indicates the potential for increased market share, ultimately incentivizing the venture with future profits and brand (or company) name recognition.

Government has the ability to incentivize commercial contracts so that contractors are motivated by increased profits to reduce costs, passing a portion of the savings along to the taxpayer. Therefore, the benefit that reduced costs and development time offers to the commercial enterprise is shared by Government. However, as will be shown later in this chapter, care must be taken when devising design guidelines in the area of purchased (off the shelf) parts.

Purchased parts are one method of reducing the cost of a system through standardization. Depending on the decisions made at critical points in an ATD project, "purchased parts" could be a "two edged sword." This might offer cost savings if the ATD proceeds to production; however, it might increase the risk of component obsolescence in ATD design if it does not proceed to production, and is

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[75] TMEH, Vol. VI, *Design For Manufacturability*, p. 1-1, SME, January 1992.

instead designated for production only in the event of defense forces' reconstitution and mobilization.

## B. WHY USE DFM?

### 1. Problems Encountered Without DFM

Probably one of the most significant reasons for the use of DFM is that of avoiding the problems associated with not using DFM in the design process. The following is partially based on a list of such problems identified by SME, and applied to ATD transition to production. When ATD production is addressed below, it assumes that the ATD has proceeded through the acquisition process to the production and deployment phase.[76]

- **Development Time.** ATDs developed without regard for existing or planned manufacturing processes will take longer to transition to production, when, and if, the decision is made to proceed to production.

- **Manufacturing Equipment.** ATDs designed without regard for typical industry manufacturing capabilities may require the use of more specialized equipment, increasing component lead times, as well as costs.

- **Production Time.** ATDs designed without the use of DFM "will take more time to build and deliver, because they may require extra steps or manual operations." "This, in turn, results in poor quality and more rework."

- **Quality.** ATDs developed without DFM methodology will "have more quality problems because they have more parts from more vendors, require more manual assembly, and may not take full advantage of factory quality control procedures which are set up for typical [manufacturing] processes." Lack of

[76] Ibid., p. 1-3.

consideration for part/system interaction may cause even more problems. Without DFM, there will be an excessive number of parts in the design, increasing the probability of quality related problems.

- **Cost.** "Quality problems and extra rework translate into higher manufacturing cost, especially if defects" get as far as deployment. "Special production machinery" and packaging requirements required for non-typical designs significantly increases contractor costs, which are subsequently passed on to the government.

- **Automation.** The emphasis of automation in the new Defense S&T Strategy and MANTECH plan, demands DFM. "Companies that automate their plants without DFM find the job is more difficult than anticipated because products have too many parts of the wrong shape that don't go together easily."

- **Just-in-time (JIT).** "JIT programs depend on parts standardization, a key element of DFM." Without DFM, companies cannot order parts in large enough quantities to allow frequent deliveries.

- **Flexible Manufacturing Systems.** Parts commonality (GT) is the foundation of FMS. Without the use of DFM, "standardization of design features" is not possible. Without standard design features, FMS is not possible.

- **Computer Aided Process Planning (CAPP).** The use of CAPP requires a CIM approach to design and development, using DFM as a prior step.

- **Computer Integrated Manufacturing (CIM).** ". . . DFM is usually the first step in CIM programs, since DFM greatly simplifies designs, reduces the number of part types and, in turn, streamlines the flow of parts in a factory." DFM, particularly Computer Aided DFM, helps to ensure successful implementation of CAM and CIM.

- **Global Competitiveness.** The rest of the competitive world (e.g., the Japanese) are using DFM very successfully. Without the use of DFM, US manufacturers involved with developing and producing defense materiel will not be competitive.

- **Dual Use Technology.** ATDs developed without DFM will not lend themselves economically to commercial applications.

## 2. The Benefits of DFM

In addition to alleviating the difficulties mentioned above, DFM has significant potential benefits for use in ATD design processes. The following is only a partial list of the potential benefits and considerations:[77]

- **Operational Performance.** DFM is only one discipline imbedded in Integrated Product and Process Development and Concurrent Engineering. It provides a design "bench mark" against which performance can be measured, and in most cases can enhance the synergistic effect of integrated disciplines in overall system design.

- **System Reliability.** Reliability will be enhanced due to increased quality through simplification, standardization, appropriate selection of materials, good product design, and ability to manufacture to the design. The objective approach used in DFM focuses the majority of effort on resolving high risk elements of the system design. This will result in enhanced system reliability.

- **Ease of Assembly.** Design For Assembly (DFA) is an element of DFM; however, DFA is what "comes to mind when most people think of DFM." DFA imposes assembly considerations on all aspects of design decision making.

- **Testability.** Test considerations, particularly quality testing, are incorporated in the DFM process, up front in the design process.

- **Maintainability.** This is a critical area for logistical supportability concerns in system design. Accessibility for maintenance purposes is easily incorporated into DFM objectives.

- **Human Factors Engineering (HFE).** This is a critical element of the concurrent engineering process, as well as DFM. HFE "should be considered at the very beginning, since ergonomic changes would be difficult to implement after the design is complete." "Good human factors design of the product and process will reduce errors and accidents in manufacture and use."

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[77] Ibid., significant portions from pp. 1-4 through 1-7.

- **Safety.** System and process safety are critical concerns throughout the process, especially early in the design process.

- **Environmental Factors.** Environmental, product and process pollution, and recycleability are areas that cannot be ignored during the design process. Environmental issues must be included in DFM objectives, early in the design process.

- **Materials Overhead (Parts Inventory) Savings.** Standardization of parts reduces the quantity of parts required in inventory during assembly, as well as the number of spare parts that must be acquired to sustain the life of the system in service.

- **Machinery Utilization Savings.** "Average machine tool utilization is about 15%". If GT changes and setup reductions have the potential to increase machine utilization (as estimated by SME) by only 15%, then overall plant capacity will be doubled. This is one of the greatest advantages of DFM.

- **Overall Development Cost Savings.** This is the most significant area. "Using DFM techniques can lower product [ATD] development budgets by 'doing it right the first time' and by avoiding 'reinventing the wheel.'" Considering all goals and constraints early will more quickly converge designers to the optimal design and result in fewer engineering change orders and much less risk of redesign.

### 3. Other Issues

One of the arguments against DFM is the "Design Freedom" argument. TMEH Volume VI states, regarding this argument:

> Designers [scientists and non-manufacturing engineers] may be tempted to think that fewer constraints mean more design freedom, and many may resist DFM on those grounds. But, in reality, too few constraints may lead to the design equivalent of writer's block. If every design decision has many open choices, the whole design will represent an overwhelming array of choices that can lead to design paralysis. So the designer breaks the impasse by making arbitrary [or optimal performance] decisions. Every arbitrary decision will probably make it difficult to incorporate other considerations later. And the

> further the design progresses (the more arbitrary decisions), the harder it will be to satisfy additional considerations.
>
> Not considering all the goals and constraints at the beginning results in arbitrary decisions that eliminate solutions downstream.

Another argument against DFM is the time required to conduct DFM planning and analysis. Many engineers under the time pressure to get a product to market first, will not want to take the time to conduct the analysis. However, the new DOD position is to allocate additional time to system development, not rushing to production. Without a significant threat to national security driving the schedule, there will be ample time to conduct DFM in an ATD.

DFM is also a learning process. Initially, DFM requires significant investments in resources and effort. However, the learning effect will reduce the amount of time and effort required with repeated use of the methodology. Also, if CADFM is incorporated into the design process (via a CIM system), learning will be automatic and institutional via the expert system.

Perhaps the greatest benefit of DFM is to measure the performance aspects of the design with reality. A tremendously astounding design in the laboratory, which cannot be produced and fielded in the event of mobilization, is useless during war. Designers must never lose sight of the user. If a system cannot be affordably produced and put into the hands of soldiers, sailors and airmen, it is useless to national defense. As Mr. Conver said, "Future wars are likely to be 'come

as you are' affairs; the existence of superior technology in the laboratories will be of no use in winning in those engagements."

### 4. The Potential Cost Effects of DFM

DFM can cause a significant reduction in the manufacturing costs of a given product. The key to taking maximum advantage of DFM is in influencing the design process, early on. TMEH, Volume VI, states:

> By the time a product has been designed, only about 8% of the total product budget has been spent. But by that point, the design has determined 80% of the lifetime cost of the product! (See [Figure 12]). The design determines the manufacturability, and that determines a significant part of the introduction and production cost, the 80% of the product. Once this cost is locked in, it is very hard for manufacturing to remove it. Cost reduction programs should start with product design, because it has the most influence over the design's overall cost.[78]

The greatest problem with producibility efforts in DOD acquisition efforts is that, when producibility assessment (a part of DFM) is conducted, it is frequently not conducted until the EMD phase. The Navy *Best Practices* manual repeatedly states that review of the producibility effort should be conducted "during FSD [EMD]."[79] This is too late in the development process to initiate a producibility effort, because there is little design flexibility at this stage in the development. Figure 13 reflects this decrease in design flexibility as a function of time.

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[78] Ibid., p. 1-4.

[79] Department of the Navy, NAVSO P-6071, *Best Practices: "How to Avoid surprises in the World's Most Complicated Technical Process." The Transition from Development to Production*, e.g., pp. 6.1, 10.1, March 1986.

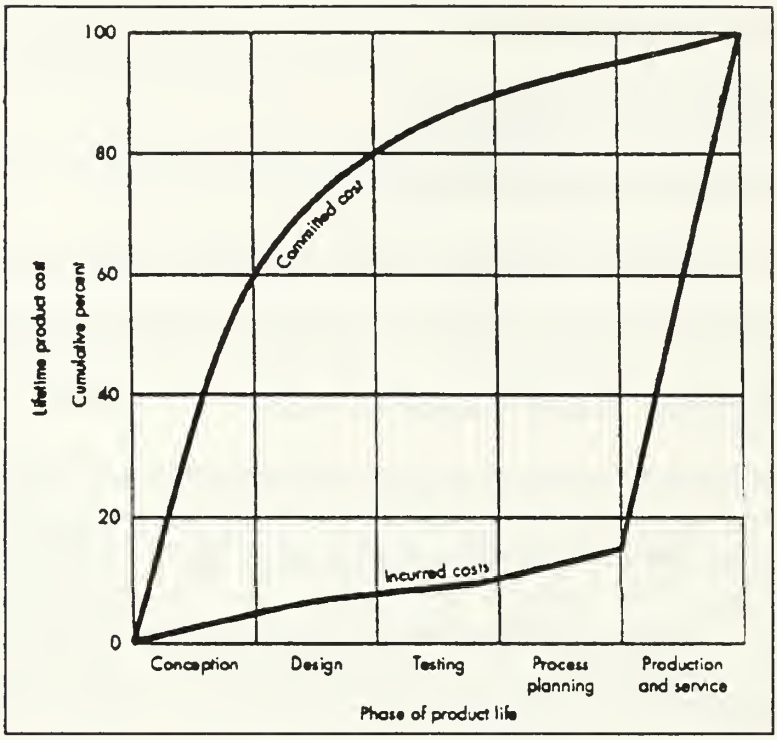


**Figure 12** Product Costs as a Function of Time (TMEH, Vol. VI, p. 1-4).

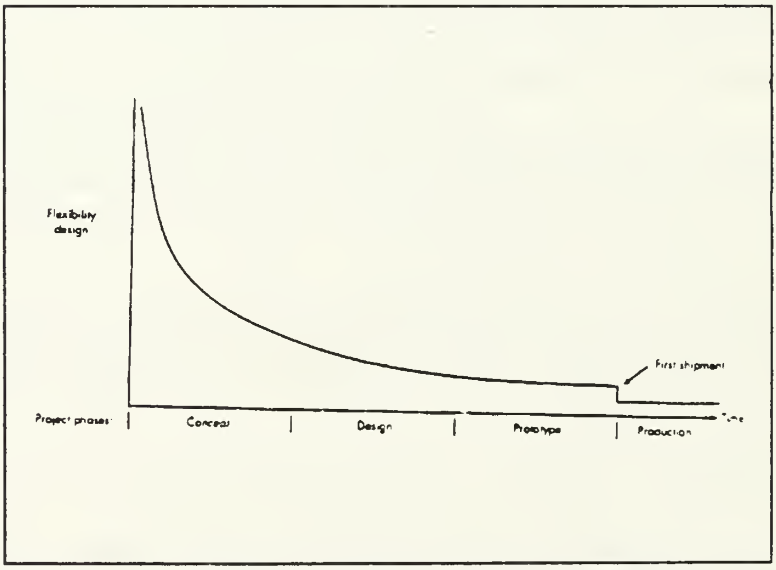


**Figure 13** Design Flexibility (TMEH, Vol. VI, p. 10-3).

DFM must be conducted early and throughout the design and development process, which implies that manufacturing should be represented on the design team. Figure 14 below shows the appropriate "level of activity" for an adequate DFM effort. The greatest DFM level of effort should occur during DEMVAL, which is the preliminary design phase. In terms of an ATD project, the greatest level of DFM effort occurs during system modeling and simulation.

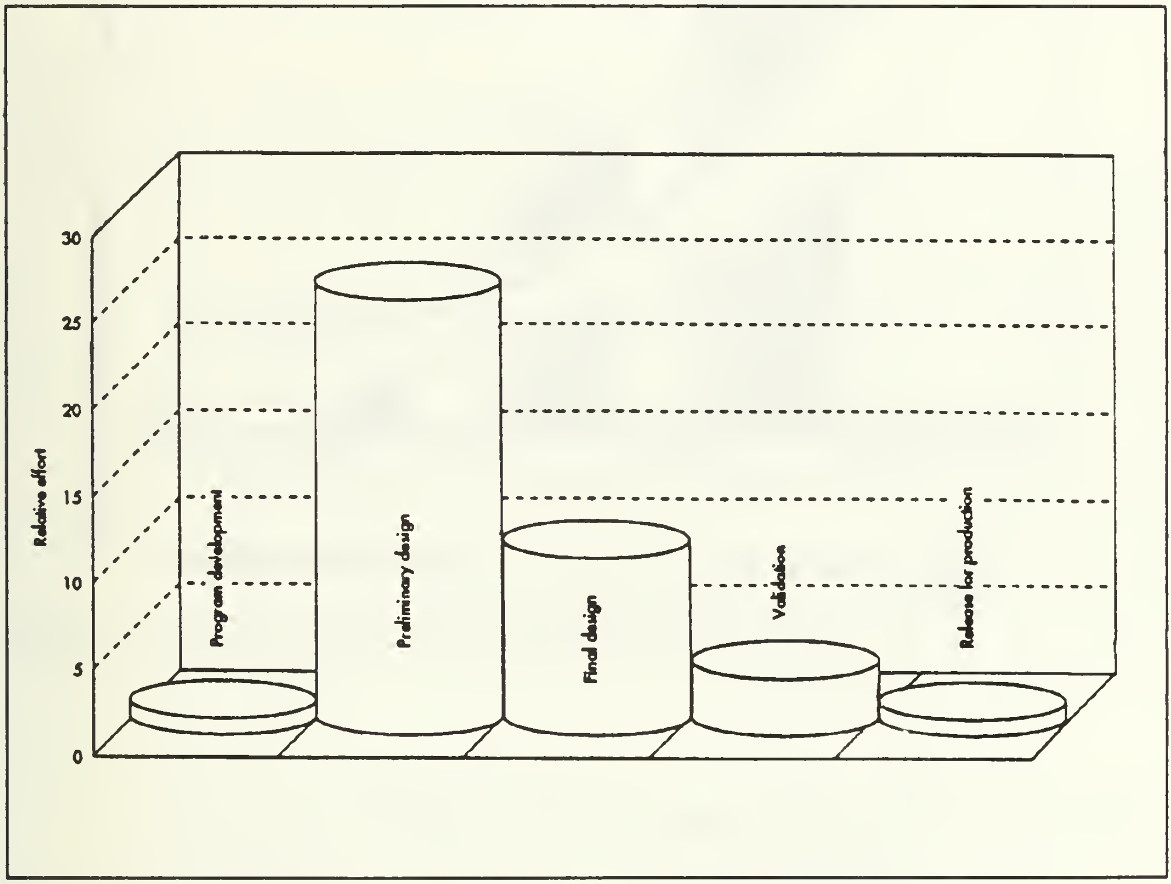


**Figure 14** Level of Activity for DFM Effort (TMEH, Vol. 6, p. 5-2).

Therefore, the greatest potential for ATD manufacturing cost reduction occurs early in the CE phase. As a system progresses from phase to phase, DFM methodology Cost Reduction Potential (CRP) diminishes. Figure 15 graphically depicts this change in CRP as a function of project phases.

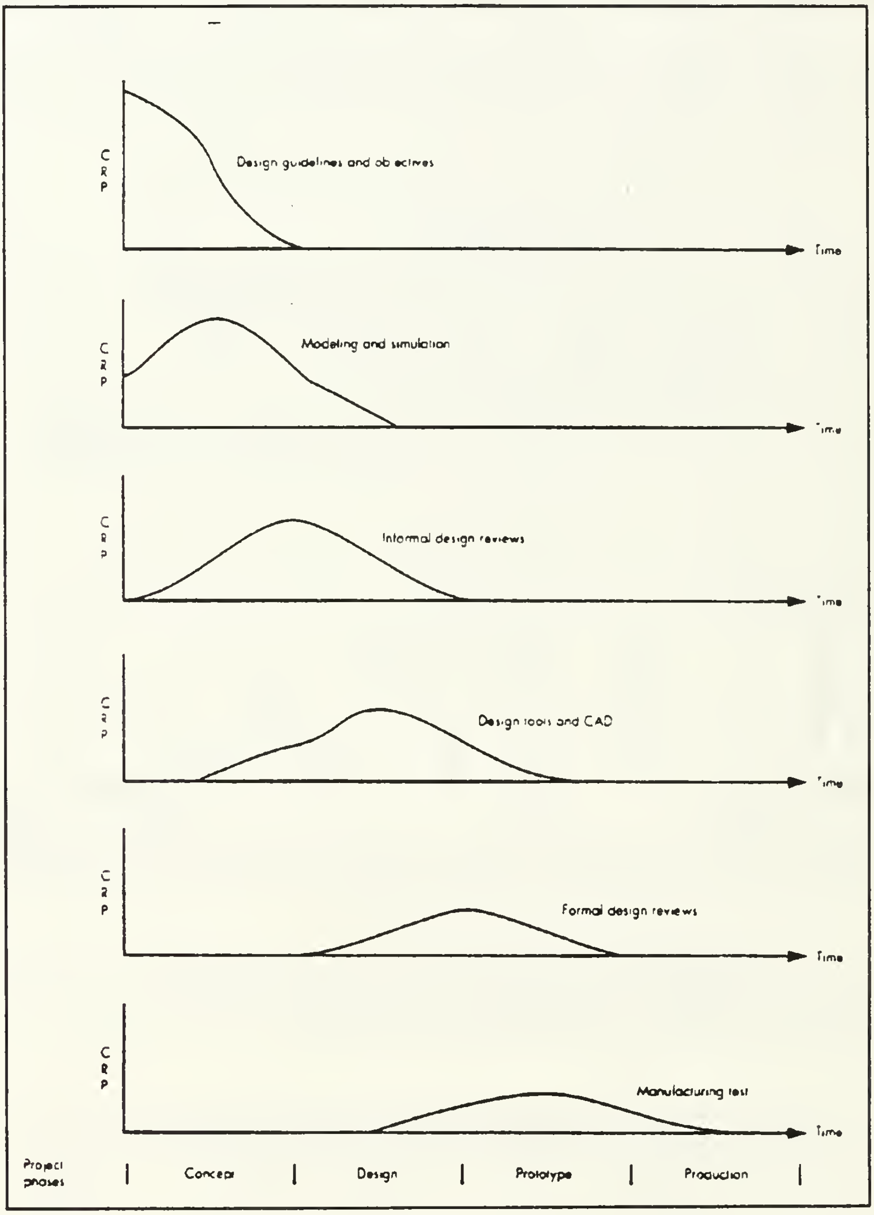


**Figure 15** DFM Cost Reduction Potential (TMEH, Vol. VI, p. 10-13).

Changes, as a result of DFM, later in a project become increasingly expensive from phase to phase. Figure 16 shows the magnitude of design change costs, to correct for manufacturability concerns, as a function of time.

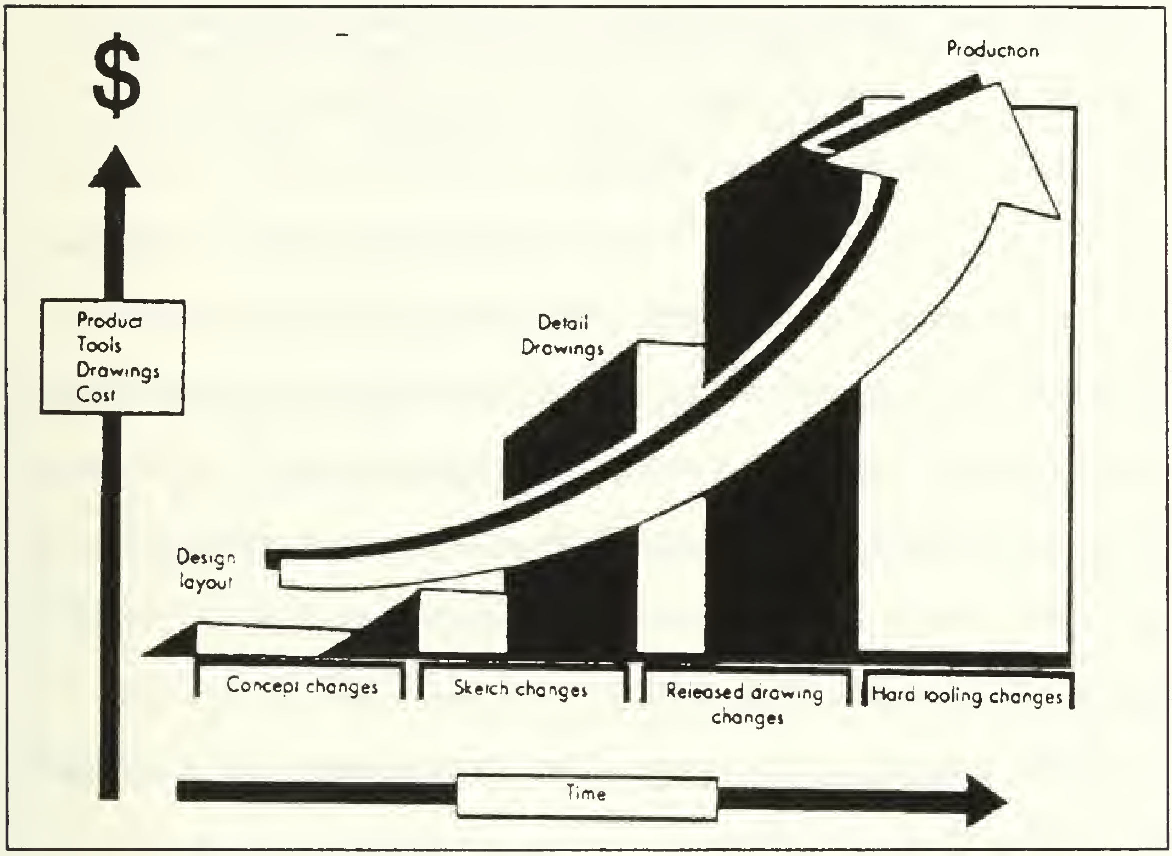


**Figure 16** Design Change Effects on Cost (TMEH, Vol. VI, p. 10-50).

In order to be used to its maximum potential, DFM must be incorporated early in the development of an ATD. This will significantly increase the manufacturability of an ATD upon transition to production.

## C. DFM AS AN ELEMENT OF CONCURRENT ENGINEERING

Concurrent engineering (CE) is defined in DSMC's *Glossary of Defense Acquisition Acronyms and Terms* as:

> A systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause developers, from the beginning, to consider all elements of the system life cycle from requirements development through disposal, including cost, schedule and performance.

DFM is a crucial element of Concurrent Engineering (CE). According to TMEH, it is a "core part" of concurrent engineering and "its concepts are based on an expanded focus of the entire product life cycle from concept development through use and disposal."[80] It goes on to emphasize that the basis of CE is in Integrated Product and Process Development (IPPD). Concurrent development of manufacturing and support processes along with product design is the chief cornerstone of concurrent engineering.

TMEH provides a list of the **"Ten Commandments of Concurrent Engineering."**[81] They are as follows:

- **Understand your customer.**
- **Use product development teams.**
- **Integrate process design.**

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[80] Ibid., p. 2-1.

[81] Ibid., p. 2-2.

- **Involve suppliers and subcontractors early.**
- **Use digital product models.**
- **Integrate CAE, CAD, and CAM tools.**
- **Simulate product performance and manufacturing processes electronically.**
- **Use quality engineering and reliability techniques.**
- **Create an efficient development approach.**
- **Improve the design process continuously.**

These "ten commandments of CE" form the basis of the methodology. The emphasis is on the integration of disciplines in a single process, to alleviate the potential for sub-optimized design specifications. Continuous improvement of the CE process ensures new developments in technologies and methodologies are considered for adoption into current CE practices.

Since DFM is a chief element of CE, there are also axioms that have been developed to ensure the continuous improvement of this methodology. There are nine basic principles of DFM:[82]

- Simplify and reduce the number of parts because for each part, there is an opportunity for a defective part and an assembly error.
- Standardize and use common parts and materials to facilitate design activities, to minimize the amount of inventory in the system, and to standardize handling and assembly operations.

[82] Ibid., p. 2-4.

- Design for ease of fabrication. Select processes compatible with the materials and production volumes. Use near net shapes for molded and forged parts to minimize machining and processing effort. Avoid unnecessarily tight tolerances that are beyond the natural capability of the manufacturing processes. **[Challenge potentially unnecessary Military Standards!]**

- Mistakeproof product design and assembly so that the assembly process is unambiguous.

- Design for parts orientation and handling to minimize nonvalue-added manual effort and ambiguity in orienting and merging parts.

- Minimize flexible parts and interconnections.

- Design for ease of assembly by utilizing simple patterns of movement and minimizing the axes of assembly.

- Design for efficient joining and fastening.

- Design modular products to facilitate assembly with building block components and subassemblies.

The most critical aspect of the design is that of IPPD. The design cannot be limited to CAD geometries, drawings and parts lists. It should also specify critical manufacturing process information like:

- Specification, design and layout of production equipment and processes.

- Process plans to define how the product will be manufactured with the given production processes and capabilities.

- Parts and subassembly programming (for example, NC, robotic, insertion equipment, coordinate measuring machines, vision and computer-aided test equipment).

- Tool and fixture design.[83]

[83] Ibid., p. 2-14.

Integrating all of these aspects of the IPPD is the critical issue here. TMEH states:

> When product design data is developed and released, process design data must be similarly developed and released in this type of integrated environment. This will assure that when a new part is introduced or an engineering change is made, the electronic release for production includes the correct process plans, tool requirements, and parts programs for the latest configuration and process capability. As computer-aided manufacturing technology is utilized and integrated with the digital product model, part geometry and process information can be passed directly to production process equipment in direct numerical controlled (DNC) fashion.[84]

Figure 17 graphically depicts the integration of product data with manufacturing process development. IPPD has significant potential to reduce both system cost, and design and production cycle time requirements.

Therefore, in order to achieve many of the automated and integrated improvements set forth in the Defense S&T Strategy and the national MANTECH plan (particularly the seven thrusts, and especially technology for affordability), systems integration is paramount. This process also provides a framework for ensuring the continued producibility of an ATD which has had development suspended. This issue will be addressed in Chapter V.

## D. PRODUCIBILITY ASSESSMENT (PA) METHODOLOGY

As stated in Chapter II, the DSMC glossary of *Defense Acquisition Acronyms & Terms* defines producibility as:

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[84] Ibid., pp. 2-14 through 2-15.

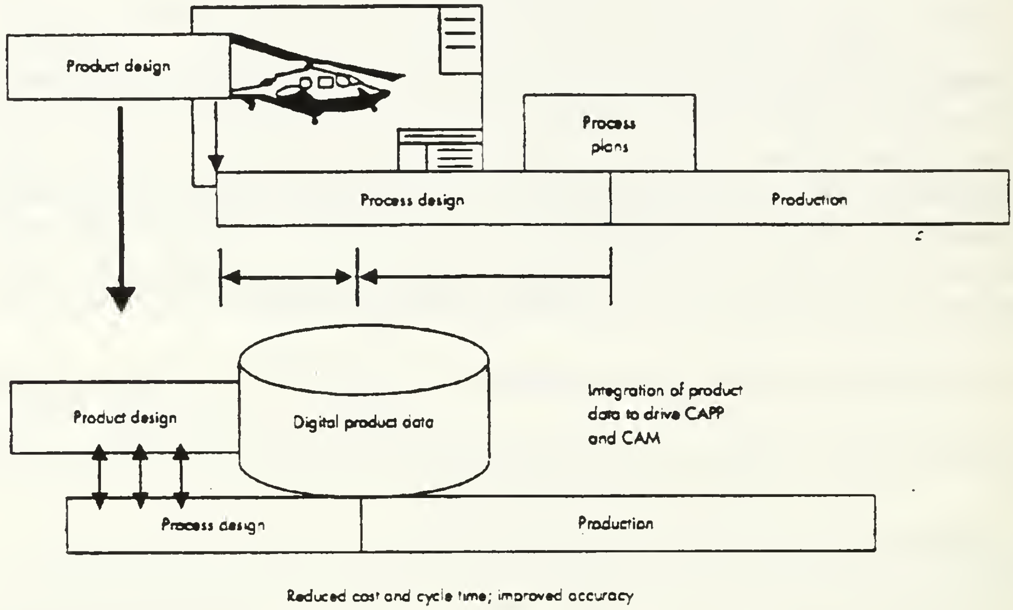


**Figure 17** Integrated Product and Process Development, (TMEH, Vol. VI, p. 2-14).

> The relative ease of manufacturing an item or system. This is governed by the characteristics and features of a design that enable economical fabrication, assembly, inspection, and testing using available manufacturing techniques.

Producibility assessment, one of the quantitative tools available under DFM methodology, must be incorporated at the beginning of a project (or ATD) to be effective (see previous section). If it is not used, early on, there are potentially serious ramifications (e.g., cost and schedule) during the EMD and, production and deployment phases of a project.

Producibility integrates the essential manufacturing elements of product design, manufacturing process, and materials into a directed, simultaneous effort. SME refers to the area in which these three elements are optimally controlled as the "Region of Producibility."[85] Figure 18 graphically depicts the integration of these elements. Conducting a thorough PA will help to identify and minimize those areas of risk in design, process and material, while optimizing the "region of producibility."

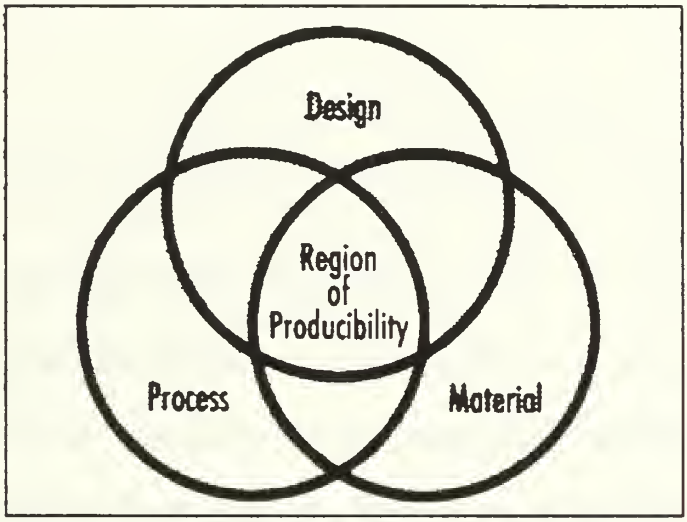


**Figure 18** Three Major Factors of Producibility (Producibility Handbook, p. 33).

Perhaps the most significant benefit of a thorough PA is a smooth transition from development to production. According to TMEH, Volume VI, there are several benefits that industry can anticipate as a result of PA:

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[85] Office of the Assistant Secretary of the Navy (RD&A) PI, *Producibility Measurement for DOD Contracts, or "How can I make what the government wants without losing my shirt?"*, Best Manufacturing Practices Program, Washington, D.C., 1992.

- More complete and competitive proposals can be issued.

- Problems that could arise during production are identified early, and corrective actions taken before the problems prove costly.

- There is an emphasis on design to achieve optimum, cost-effective production.

- Subcontractor abilities and deficiencies are clarified.

- Product quality, reliability, and maintainability are improved.

- New technologies needed to achieve producibility may be identified and explored.

- Products can be delivered on schedule and within cost.

- There is a greater opportunity for more profitable production or lower cost to customer.[86]

The benefits listed above are shared by DOD. PA methodology, while reducing program risk, also reduces the potential for cost overruns, required changes during production and after deployment, and total life cycle costs.

There are costs directly associated with adopting a DFM (including PA) methodology in ATD development. TMEH, Volume VI, states:

> There is cost involved with producibility assessment. It requires additional training, dedicated resources such as computers and data collection systems, and possibly additional manpower. But producibility assessment (PA) is worth its cost. Companies with proven producibility assessment programs have experienced improvements such as: 30% reduction in product development time and cost, 50% reduction in design changes, 70% reduction in engineering changes after a part is released for production, 30%-50% reduction in labor costs and time between design and production, and 80% reduction in rework.

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[86] TMEH, Volume VI, *Design For Manufacturability*, p. 10-33, SME, January 1992.

With results like that, the costs associated with producibility assessment are returned many times over.[87]

A concurrent engineering team approach is the most effective method for conducting PA. TMEH recommends the CE team include producibility, design, manufacturing, software and systems engineers. Experts in quality assurance, materials management, testing and evaluation, and logistics supportability should also be included.[88]

One highly effective method of conducting a PA is through the use of established Producibility Assessment Worksheets (PAW). The handbook, *Producibility Measurement for DOD Contracts*, provides four discipline specific PAWs and one universal PAW.[89] Figure 19 and Figure 20 are two examples of the five PAWs provided in this handbook.

Each PAW can be used to assess the producibility of a part, component or subsystem of an ATD or weapon system. For each assessment, alternate production methods are evaluated (e.g., PM#1 through PM#4) against specific criteria (A1 through A5). Each production method is then given a quantitative producibility

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[87] Ibid., p. 10-34.

[88] Ibid., pp. 10-33 through 10-34.

[89] Office of the Assistant Secretary of the Navy (RD&A) PI, *Producibility Measurement for DOD Contracts, or "How can I make what the government wants without losing my shirt?"*, Best Manufacturing Practices Program, Washington, D.C., 1992.

# CIRCUIT CARD ASSEMBLY

**Producibility Assessment Worksheet**

**Assessment Candidate** ______________________________

**Production Method (PM)** ______________________________

**1.** ______________________________

**2.** ______________________________

**3.** ______________________________

**4.** ______________________________

| | Method | PM #1 | PM #2 | PM #3 | PM #4 |
|---|---|---|---|---|---|
| **A1 Design** | | | | | |
| .9 Existing standard 2 sided PC board | | ____ | ____ | ____ | ____ |
| .7 Existing standard multilayer card | | ____ | ____ | ____ | ____ |
| .5 Multilayer card, high thermal loads | | ____ | ____ | ____ | ____ |
| .3 Multilayer card, high thermal, hard to wire | | ____ | ____ | ____ | ____ |
| .1 Highly complex unproven design | | ____ | ____ | ____ | ____ |
| **A2 Raw card fab process/environmental impact** | | | | | |
| .9 Similar cards in current production | | ____ | ____ | ____ | ____ |
| .7 Previous experience on similar cards | | ____ | ____ | ____ | ____ |
| .5 Process available-no experience | | ____ | ____ | ____ | ____ |
| .3 Process develop, req.'d, possible env. risk | | ____ | ____ | ____ | ____ |
| .1 Completely new process or high env. risk | | ____ | ____ | ____ | ____ |
| **A3 Materials/electrical components** | | | | | |
| .9 Readily available/off-shelf components | | ____ | ____ | ____ | ____ |
| .7 1-3 month order some components | | ____ | ____ | ____ | ____ |
| .5 3-9 month order some components | | ____ | ____ | ____ | ____ |
| .3 9-12 month order/special ord. components | | ____ | ____ | ____ | ____ |
| .1 12-18 month order/new VHSIC chip | | ____ | ____ | ____ | ____ |
| **A4 Card assembly process** | | | | | |
| .9 Complete assembly by automated equipment | | ____ | ____ | ____ | ____ |
| .7 Some manual assembly | | ____ | ____ | ____ | ____ |
| .5 Completely manual assembly | | ____ | ____ | ____ | ____ |
| .3 Complex manual assembly/adjustments | | ____ | ____ | ____ | ____ |
| .1 Controlled environment/complex assembly | | ____ | ____ | ____ | ____ |
| **A5 Inspection/testing** | | | | | |
| .9 Can be auto tested/insp. using std auto equip. | | ____ | ____ | ____ | ____ |
| .7 Requires special test equipment for auto test | | ____ | ____ | ____ | ____ |
| .5 Manual test/inspection with lab instruments | | ____ | ____ | ____ | ____ |
| .3 Test/inspection requires eng. development | | ____ | ____ | ____ | ____ |
| .1 Testing/inspection method undefined | | ____ | ____ | ____ | ____ |

Producibility Assessment Ratings PM #1 ________ PM #2 ________ PM #3 ________ PM #4 ________

For each Method $\frac{(A1 + A2 + A3 + A4 + A5)}{5}$ = Producibility Assessment Rating for that Method

**Figure 19** Circuit Card PAW (Producibility Handbook)

# MANAGEMENT

**Producibility Assessment Worksheet**

**Assessment Candidate** ______________________________

**A1 Funding**

| | | |
|---|---|---|
| .9 | Funding matches projected budget | ______ |
| .7 | Funding adequate, budget does not exceed 5%, cost manageable | ______ |
| .5 | Funding minimal, budget exceeds 15%, overruns likely | ______ |
| .3 | Funding sketchy, no commitment, overrun highly predictable | ______ |
| .1 | Funding inadequate | ______ |

**A2 Producibility**

| | | |
|---|---|---|
| .9 | Producibility assessment implemented before contract award | ______ |
| .7 | Producibility implemented after PDR | ______ |
| .5 | Producibility implemented after CDR | ______ |
| .3 | Producibility implemented after FSD | ______ |
| .1 | Producibility not considered | ______ |

**A3 Risk assessment**

| | | |
|---|---|---|
| .9 | Risk is manageable and predictable, risk management plan in place | ______ |
| .7 | Risk is low for program | ______ |
| .5 | Risk is medium for program | ______ |
| .3 | Risk is high for program | ______ |
| .1 | No risk management plan or policy for risk management exists | ______ |

**A4 Data requirements**

| | | |
|---|---|---|
| .9 | All necessary specs/CDRLS have been negotiated into contract | ______ |
| .7 | Tailoring of all specs/CDRLS is accomplished | ______ |
| .5 | All specs/CDRLS cost drivers identified | ______ |
| .3 | Only major specs/CDRLS cost drivers identified | ______ |
| .1 | No identification of spec/CDRLS cost drivers | ______ |

**A5 Transition planning**

| | | |
|---|---|---|
| .9 | Company policies comply with guidelines of DOD 4245. 7-M | ______ |
| .7 | Transition planning commences at concept phase | ______ |
| .5 | Transition planning commences after DEM/VAL (DSARC phase I) | ______ |
| .3 | Transition planning commences after FSD (DSARC phase II) | ______ |
| .1 | No transition planning | ______ |

$$\text{Producibility Assessment Rating} = \frac{A1 + A2 + A3 + A4 + A5}{5}$$

**Figure 20** Overall Management PAW (Producibility Handbook).

assessment rating, based on the formula at the bottom of each PAW. One of two decisions should be made at this point. Either, (1) the production method with the highest score is selected, or (2) consider means of improving other alternatives with lower ratings.

Producibility assessment ratings of the components or subsystems of an ATD or weapon system can be used to determine the overall system producibility. They can also be used to identify those components that most adversely affect the system producibility, so that either changes can be made in the design, or actions can be taken to improve the producibility of that particular component.

Quantitatively, the same methods used for computing and estimating system reliability, can be used for producibility. Each element of the functional system structure is assigned a producibility assessment rating based on individual PAWs. Working from the lowest levels of the system, to the highest levels of the system, an overall system producibility assessment rating can be determined by solving each branch as series, parallel or combination producibility assessment values (like reliability calculations). This approach is an invaluable tool in system design for manufacturability.[90]

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[90] There are also more extensive, quantitative methods explained in TMEH that are not discussed in this thesis.

## E. REPRESENTATIVE PRODUCIBILITY ASSESSMENTS

Producibility Assessment (PA) should be incorporated into the development of all ATDs and systems. TMEH, Volume VI, states:

> Producibility is defined as a measure of the relative ease of manufacturing a product. Every year, of the thousands of proposals submitted to the Department of Defense (DOD), most fail to adequately address whether the company has the capability and commitment to design and manufacture the product so that it can be made in quantity with a high degree of quality, reliability, and maintainability in the finished item. Often, the procuring DOD activity and the manufacturer do not recognize these flaws until well after the contract has been awarded. In many cases this over sight is not recognized until development or production is proceeding.
>
> The solution to this problem is producibility assessment (PA). Failure to properly assess producibility can affect performance awards and subsequent buys, increase rework costs, and generate costly redesign actions. . . It is used by DOD activities as a proposal evaluation discriminator, to assess the contractor's ability to effectively plan and manage the entire development and manufacturing process. It is a critical part of the design process.[91]

Applying PA methodology to previous or existing acquisition programs will help to clarify its usefulness in weapon system and ATD design processes. The following sections may provide some insight regarding potential PA benefits. Both the Navy's cancelled A-12 program and the Army's existing Comanche program required advanced composite structures in airframe design in order to meet low observability requirements. Composite structures require highly advanced manufacturing process capabilities, and therefore, potentially introduce an increased producibility risk in the design.

[91] Ibid., p. 10-32.

### 1. The A-12

The Navy's cancelled A-12 program is an excellent example of poor producibility assessment early and throughout a program. One of the most critical technologies in the A-12 program was the manufacture of the composite air frame and components. Stealth technology uses composite materials to reduce or eliminate the radar signature of aircraft. Therefore, the question here is one of the state of design and manufacturing technological capability.

As pointed out in Chapter II, neither McDonnell Douglas (McAir), nor General Dynamics (GD), had much experience with manufacturing processes for large composite structures. As late as the EMD (FSD) phase, McAir and GD were struggling with these processes. Having made a mistake in the initial minimum design thickness of the composite material required to bear sufficient stress and loads, seriously exacerbated this problem.

The question arises regarding methodology that might have enabled the Government to avoid this problem with the A-12. As an example, the following is a producibility assessment limited to the A-12 composite structural design. The following mock PA is based only on information presented in the Beach report.

## Producibility Assessment Worksheet
**A-12 Composite Structure (Illustration)**

**A1 Design**
.9 Existing/simple design
.7 Minor redesign/increase in complexity
.5 Major redesign/moderate increase complexity
.3 Tech. avail. complex design/significant increase
.1 State-of-the-art research req./highly complex

**A2 Process**
.9 Process is proven and technology exists
.7 Previous experience with process
.5 Process experience available
.3 Process is available, but not proven yet
.1 No experience with process, needs R&D

**A3 Materials (availability/machinability)**
.9 Readily available/aluminum alloys
.7 1-3 month order/ferrous alloys
.5 3-9 month order/stainless steels
.3 9-18 month order/non-metallic (smc, etc.)
.1 18-36 month order/new R&D material

**A4 Design to cost (DTC)**
.9 Budget not exceeded
.7 Exceeds 1-5% in DTC
.5 Exceeds 5-20% in DTC
.3 Exceeds 20-50% in DTC
.1 Cost DTC goals cannot be achieved

**A5 Schedule Compliance**
.9 Negligible impact on program
.7 Minor slip (<1 month)
.5 Moderate slip (1-3 months)
.3 Significant slip (3-5 months)
.1 Major slip (>5 months)

**Producibility Assessment Rating** = (A1+A2+A3+A4+A5) ÷ 5 = **14 % Rating**
(or 86 % Risk Rating - MFG Process)

Granted, this level of objective information may not have been available early in the program. However, a concurrent engineering team (both Government and contractor) would certainly have calculated a poor PA rating on the composite structure. Producibility risk in this case is extremely high at 86%; it was probably assessed officially as moderate. Perhaps the contractors were well aware of this rating.

Given more time to develop the design concurrently with the process, as well as exhaustive simulation, the producibility rating may have been significantly different. However, this is indicative of the times. The Soviet threat forced performance and schedule far ahead of affordability considerations. It is this type of situation that the new flexible acquisition strategy seeks to avoid by alleviating schedule pressure.

Under the ATD process, the producibility of this aircraft would have improved significantly over time. In fact, composite manufacturing process technology is being developed under the new MANTECH plan and S&T strategy. Hopefully there will not be a recurrence of this specific problem in a major program.

### 2. The "Comanche" RAH-66 Helicopter

The Comanche helicopter project underwent restructuring according to the new flexible acquisition strategy, as directed by the Bush administration in January 1992. The following is an excerpt from a House Armed Services Committee

news release on October 1, 1992. It reports FY93 Defense Authorization Bill funding of Comanche:

> The FY93 Pentagon budget included $443 million in research and development funds to continue prototype development of the Comanche. The House bill approved the request.
>
> The Senate, on the other hand, terminated the program based on a new Administration acquisition strategy that abandoned plans to take the Comanche beyond the prototype stage [ATD]. The Administration sought a total of $1.9 billion to develop three Comanche prototypes.
>
> The conferees reiterated their support for prototyping but found the Administration's prototyping plan too expensive to complete without a funded plan to finish development of the Comanche. However, the conferees noted that budgeting full development of the Comanche does not represent a commitment to proceed to production.
>
> The conferees approved the Administration request.[92]

A reliable source involved with Comanche stated that the Army had been directed (off line) to obtain funding for the Comanche or kill the project; it would not proceed under the auspices of an ATD, with R&D funds. Although the Army was able to fund the project as full development, its status is questionable under the recent budget cuts directed by Secretary of Defense, Les Aspin.

The revised acquisition plan for Comanche (as of August 1992) stated:

> <u>Producibility.</u> Even though producibility efforts have been reduced during the Dem/Val Prototype phase, certain tasks remain in order to continue the concurrent producibility-design influence. This basic effort will be accomplished through the Product Development Team (PDT) concept. In

---

[92] HASC News Release, p. 9, FY93 Defense Authorization Bill, October 1, 1992.

order to prepare for the eventuality of aircraft production, the Boeing Sikorsky team will continue to conduct a producibility program, using Army Regulation (AR) 70-72 as a guide. . . . The contractors will also continue integration of producibility and design-to-cost (DTC) activities, support of program risk management activities, and accomplishment of appropriate planning activities to support a successful transition into the next phase.

It appears that, in order to cut costs under the Comanche program restructuring, the Army is not requesting any deliverable documents on producibility of the aircraft. Producibility efforts, Design to Cost (DTC) integration and risk management activities are being addressed on a quarterly basis, without accompanying deliverables. Not funding producibility efforts has potentially serious, long range implications.

Previously, defense contractors provided up front funding to cover the cost of DFM. This was typically in anticipation of profits resulting from full scale production and life cycle support. When proceeding to production is a questionable issue, contractors are very reluctant to "foot the bill" for producibility. In a situation like the Comanche, funding of producibility efforts is very important.

Also under the restructured program, the previously proposed 2,096 aircraft quantity was reduced to 1,292 aircraft, at a peak production rate of 120 per year, as opposed to 216 per year under the previous plan. This reduction in quantities could have a significant impact on DTC objectives, and optimal manufacturing process quantities.

When assessing technological risks, the Comanche air vehicle (a composite structure) was assessed as low to moderate risk. Boeing has a significant amount of experience in manufacturing composite structures based on the Air Force's B-2 program; however, B-2 quantities are an order of magnitude smaller than Comanche. Producibility risk was assessed as moderate.

The following mock PA of the Comanche composite airframe is based only on the above mentioned, probably now obsolete, information.

## Producibility Assessment Worksheet
**Comanche Composite Air Frame (Illustration)**

**A1 Design**
.9 Existing/simple design
.7 Minor redesign/increase in complexity
.5 Major redesign/moderate increase complexity
.3 Tech. avail. complex design/significant increase ☜
.1 State-of-the-art research req./highly complex
**A2 Process**
.9 Process is proven and technology exists
.7 Previous experience with process ☜
.5 Process experience available
.3 Process is available, but not proven yet
.1 No experience with process, needs R&D
**A3 Materials (availability/machinability)**
.9 Readily available/aluminum alloys
.7 1-3 month order/ferrous alloys
.5 3-9 month order/stainless steels
.3 9-18 month order/non-metallic (smc, etc.) ☜
.1 18-36 month order/new R&D material
**A4 Design to cost (DTC)**
.9 Budget not exceeded
.7 Exceeds 1-5% in DTC
.5 Exceeds 5-20% in DTC ☜
.3 Exceeds 20-50% in DTC
.1 Cost DTC goals cannot be achieved
**A5 Schedule Compliance**
.9 Negligible impact on program ☜
.7 Minor slip (<1 month)
.5 Moderate slip (1-3 months)
.3 Significant slip (3-5 months)
.1 Major slip (>5 months)

**Producibility Assessment Rating =** $(A1+A2+A3+A4+A5) \div 5 =$
**54 % Rating**
(or 46 % Risk Rating - MFG Process)

Given funding as a full development acquisition project and sufficient time and funds for the producibility effort, the Comanche PA rating should continue to grow; however, 54% is probably less than desirable. A 46% risk rating might be considered moderate to high. Current fiscal uncertainties may make this a moot issue altogether.

## F. COMPUTER AIDED DFM (CADFM)

The quantitative approach to PA, also lends itself readily to Computer Aided DFM (CADFM). CADFM is also referred to as an "integrated producibility assessment system." TMEH explains this integrated system in the following way:

> A conceptual design of an integrated producibility assessment system is depicted in [Figure 21]. The methodology starts by importing a part design from a CAD package via a standard data exchange format such as PDES (Product Data Exchange Specification). First, a series of feature recognition rules are applied to extract various manufacturing and geometric features from the part design. Then, the system consults with the six manufacturing knowledge bases (materials, assembleability, standards, etc.) to select the best material and the best process to meet the specifications. It analyzes all the producibility aspects of the part, calculates the producibility indexes, and recommends the best method for manufacturing. It also suggests alternatives which can improve the producibility index if some design parameters can be changed. With such a tool, designers can rapidly evaluate several design options and pick an optimum design which satisfies all the criteria and is highly producible.[93]

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[93] TMEH, Volume VI, *Design For Manufacturability*, pp. 10-31 through 10-32, SME, January 1992.

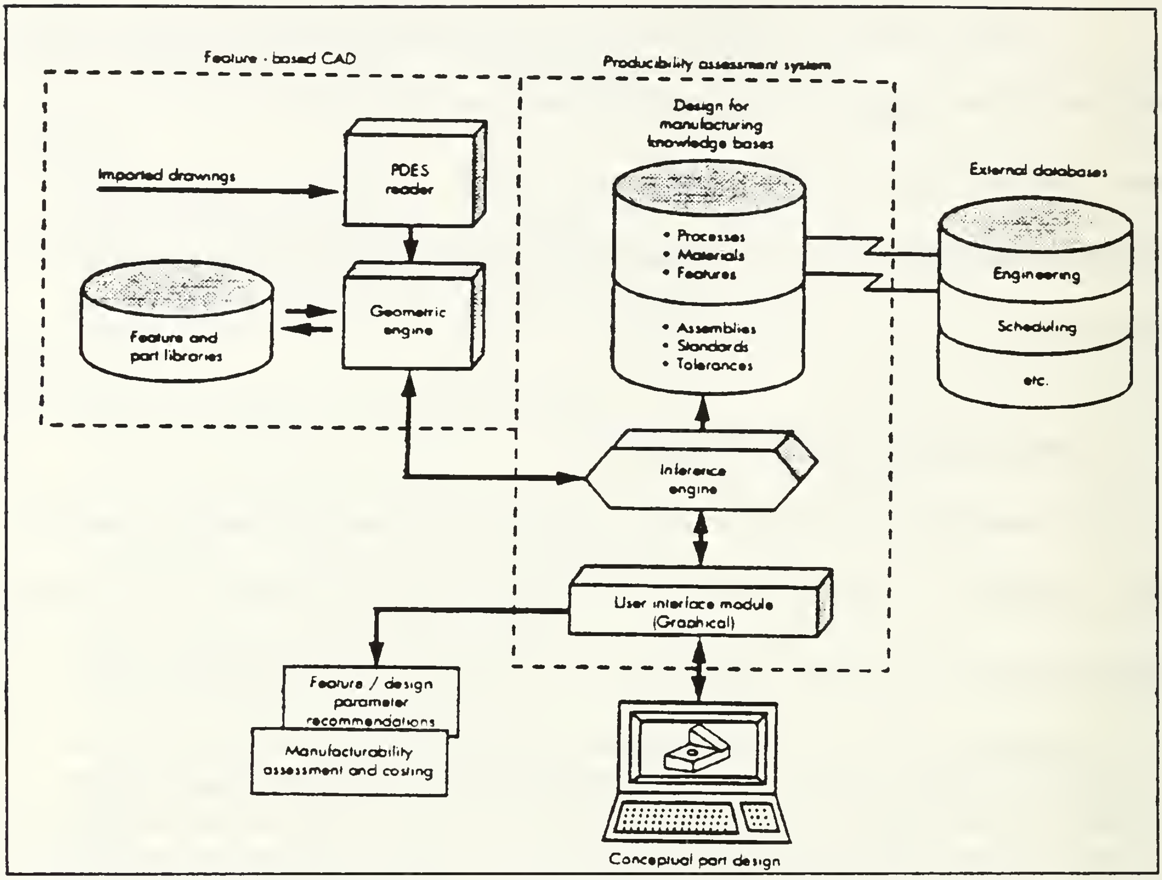


**Figure 21** Conceptual Computer Aided DFM (TMEH, Vol. VI, p. 10-32).

Automated tools like this support the feasibility of the current Defense S&T Strategy and national MANTECH plan. Integrated producibility analysis presents a significant potential benefit to ATD and weapon systems development. It can also be integrated into CIM systems, and potentially a "virtual company" as well.

# V. ENSURING ATD PRODUCIBILITY

## A. EFFECTS ON SYSTEM PRODUCIBILITY OF SUSPENDING DEVELOPMENT AFTER ADVANCED TECHNOLOGY DEMONSTRATION

As stated in Chapter III of this thesis, there are three criteria, regarding ATD development, that must be met before proceeding as an acquisition system:

- The technology must have been demonstrated, thoroughly tested, and shown to be producible.
- There is a clear and verified military need [current threat] for the new system or system upgrade.
- The new system or system upgrade is cost effective.[94]

The question arises from these criteria regarding disposition of an ATD project that meets only the first and third criteria above. As discussed in Chapter III, when this occurs, a decision must be made whether to continue to develop the system or technology (requiring additional funds), abandon it or "put it on the shelf."

If the technology has been "demonstrated, thoroughly tested, and shown to be producible," there is no need to continue to develop the ATD. However, if there is a potential future threat, a technology that meets the first and third criteria is a prime candidate for the reconstitution concept, described in the National Military Strategy.

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[94] USD(A) White Paper, *Defense Acquisition*, p.3, May 20, 1992.

An ATD that is designated for reconstitution acquisition only, would be one formerly referred to as being "put on the shelf." Such an ATD would have development suspended, pending reconstitution or redevelopment. This might have been accomplished assuming some sort of periodic or event driven review process.

An ATD that meets the first and third criteria for proceeding to acquisition, but development is suspended for whatever reason(s), ought to be addressed. For the sake of analysis, this thesis will refer to this situation as Suspended ATD development (SATD), as opposed to a "shelved" or "hovering" ATD. Cost effectiveness, as stated in the third criterion, is driven predominantly by affordability and Life Cycle Cost (LCC) issues. The following analysis is focused on the producibility aspects of affordability.

SATD would probably have the following effects on producibility:

- Less risk involving future advanced manufacturing processes
- Material, part, component and subsystem obsolescence.
- Lower tier industrial base issues.
- Design Obsolescence.
- Increased manufacturing costs.

Perhaps the greatest benefit associated with an SATD would be **less risk involving advanced manufacturing processes.** Designs involving composite material structures, technologies like focal plane arrays and fiber optical electronic interfaces

would become more producible as industry becomes more capable in these manufacturing processes. However, technologies without accompanying commercial applications might not fare as well as those with dual use potential.

The greatest effects in terms of **material, part, component and subsystem obsolescence** would be in the areas of electronics, avionics and scarce materials. The example used in Chapter II regarding 8088 and 80286 processors is perhaps most representative of the ever changing "state of the art" in advanced technologies, although their impact on modern weapon systems' designs is questionable. The Government would still be able to acquire these components, but probably at an exorbitant price if tooling up and obsolete process restoration were required.

This raises the question of time threshold. Manufacturing processes for the 8088 processor are not that different from the 80486. An even better comparison would be in the realm of transistorized circuits, compared to integrated circuits. Transistorized circuits would be prohibitively priced since they are no longer available on the open market, compared to now "relatively obsolete," but still available first generation integrated circuits. This type of analogy indicates that market availability based on normal "industry practice" is the key.

Except for unique industrial base capabilities, an SATD of two to five years would have significantly less obsolescence than one approaching ten or fifteen years. Any SATD exceeding five years would require a periodic market and industrial base

survey, and concomitant design review. However, this will require a well thought out, long range funding plan.

**Lower tier industrial base issues** are the most difficult to predict. However, production is essential to subcontractors' survival. Designs that take advantage of commercial standard components and common industry practices will be the least effected. Those designs that involve technologies that are unique to defense will be most significantly effected.

Dual use technology would help keep the lower tier industrial base more commercially viable and ready to respond to reconstitution requirements, in the event of mobilization. Also, liberalizing limitations on the use of Government Furnished Equipment (GFE) in lower tier manufacturing concerns might also help in keeping this part of the industrial base viable and responsive. Periodic, and event driven industrial base surveys would be necessary to ensure the viability of any SATD.

**Design obsolescence** would occur in the most rapidly evolving manufacturing technological areas. In this case, DFM is like a "two edged sword." DFM is essential to any affordable weapon system design. Since manufacturing processes influence the design process up front, rapidly changing manufacturing processes would have the greatest effect on SATD producibility.

Again, periodic and event driven industrial process surveys and design reviews would be essential to ensuring SATD producibility. One might argue that, in the

event of mobilization, American industry would be able to adapt and manufacture necessary weapon systems. While this might be true, there would also be an accompanying increased lead time to retool and set up to manufacture a design involving obsolete processes; the increased manufacturing costs in this case would be extremely prohibitive.

**Increased manufacturing costs** would accompany an SATD as a function of time suspended without design review and revision. Lower tier vendors are reluctant to guarantee prices of parts, components and materials for more than six months from quotation. Costs involved with an SATD would be no different, especially if the design was not kept updated.

There are many effects in areas other than producibility that need to be addressed (e.g., doctrinal employment and operational obsolescence, etc.) to ensure that SATD is a viable alternative to production and deployment; however, those areas are beyond the scope of this thesis.

## B. ATD PRODUCIBILITY: TRANSITION TO ACQUISITION

There are several methods that should be used to enhance ATD producibility. Used together, they offer a significant, synergistic effect on system acquisition affordability. Concurrent engineering, integrated automation, standardization, CALS and CAWSA are some potential methods that could prove effective in ATD transition to Acquisition.

### 1. Concurrent Engineering (CE) in ATD Projects

Applying the "Ten Commandments of Concurrent Engineering," early and throughout an ATD project, greatly enhances the cost effectiveness of the design, manufacturability, operational suitability, reliability, availability and maintainability (RAM), and many other areas. In essence, CE helps put more "bang for the buck" in the hands of soldiers, sailors, marines and airmen.

**A CE team approach should be adopted during design and development of all ATDs.** CE helps to ensure that the product is what the user needs, and that it can be produced affordably and on schedule. CE will ensure that the design conforms to both existing and achievable manufacturing process capabilities. Integrated Product and Process Development is the chief cornerstone of the CE foundation. CE is the best means of preventing technical performance and manufacturing problems in any acquisition project. It will help to ensure a smooth transition to the EMD, and production and deployment phases.

As a "core part" of CE, DFM enables an "expanded focus on the entire product life cycle" of a potential weapon system. DFM must be incorporated to ensure ATD effective transition to an acquisition project. Although manufacturability is addressed in the Defense S&T Strategy and national MANTECH plan, process development is the primary focus. Concurrently

developing both product and process is critical to successful development; however. DFM is the methodology that links product and process.

OSD must strongly emphasize DFM as an integral, critical element of CE. There is much more required to ensure the success of ATD design than making sure that affordable processes have been developed. DFM requires a paradigm shift in the pursuit of S&T excellence.

During program management seminars at NPS, many Government PMs and PEOs have quipped :

- Stick to "Good Enough" in the design.
- "Better is the enemy of "Good Enough" in design.
- After you achieve "Good Enough" in the design, "shoot" the engineers.

The list of anecdotes goes on, but all revolve around the expense and difficulty with trying to make the design as "sexy" (technologically advanced) as possible. The problem is, how does a PM know when the design is "good enough?" DFM is the best tool to ensure that the design is "good enough."

The publication of the Defense S&T Strategy and national MANTECH plan is timely and effective, containing an effective, visionary philosophy for the development of the weapon systems of the future; however, both documents stop short of providing the necessary implementation tools. References are made

regarding manufacturability, IPPD, flexible manufacturing, modeling and simulation, but little advice on methodology is provided.

The key to success in this era of "continuous improvement" is by empowerment of the managers and decision makers in the acquisition community. PMs must be educated and empowered with the most powerful tools available in the trade. CE includes <u>both</u> IPPD and DFM. OSD should take steps to ensure that R&D Centers, PMs and PEOs understand the importance of implementing CE.

### 2. Integrating User/Developer Automation

Recently, the director of operations in an Army PEO made a critical observation regarding synthetic environments. His greatest concern was that his organization did not have adequate, automated access to the battle labs. The battle labs are an innovative approach to combat development, but they are designed predominantly from that perspective. In the future, in order to be effective as "communication vehicles," the architecture of simulation networks must integrate users with scientists, engineers, developers and manufacturers. Ineffectively integrating any of these key players, reduces the potential effectiveness of simulation and modelling. Automated systems must be fully integrated from user oriented, combat development systems with design and manufacturing systems.

This can be accomplished via CIM. DOD and the Services can learn from the successes of industry. As pointed out in Chapter III, the potential savings

associated with CIM are tremendous. It is also important to realize that CIM cannot be purchased or written into a contract. CIM is a philosophy, which demands a paradigm shift regarding the tools and methodology of product (weapon systems) development.

Object oriented models used in simulations (i.e., SIMNET and Battle Labs) should be introduced using CAD. Models (virtual prototypes) developed using CAD should be analyzed and optimized using CAE, CADFM and CAPP. The components of these models should be grouped according to process within commodities. All digital electronic products (in the form of digital technical data and information) should be produced according to OSD Computer Aided Acquisition and Logistics Support (CALS) standards. This will ensure effective interface, and will aid in integration.

If the above integration is accomplished, then integrating both virtual and physical factory floors is achievable. Strongly emphasized by the Defense S&T Strategy and national MANTECH plan, flexible manufacturing and assembly systems have tremendous potential benefits in weapon systems acquisition. However, FMS is not a panacea for cutting costs from low rate acquisition. There are still significant overhead costs associated with CAD/CAM. Designing and manufacturing one item involves many hours of engineering and management effort. Making the second

through the tenth items, is where the efficiencies are gained through FMS; the first one will still be very expensive.

### 3. Standardization

Standardization is the key. Wherever possible, common industry practices need to be incorporated into the design of an ATD if it is to be ultimately producible. Standardization is essential to integration. DOD must analyze the current system of MILSTANDARDS.

Effective and efficient industry is moving toward ISO 9000 (international) quality standards. If US industry is going to effectively compete globally, it must adopt ISO 9000 standards, and strive for certification. In all of those weapon systems' and ATD applications where an ISO 9000 standard is "good enough", it should replace a MILSTANDARD. This will significantly aid the effort to integrate DOD systems.

### 4. Computer Aided Acquisition and Logistics Support (CALS)

CALS is a very strong step in the right direction. The concept of standardizing digital formats, system protocols, logistics and acquisition planning tools is, while providing system access to all authorized users, is a highly effective effort.

Army CALS initiatives are designed to:

- Implement DOD policy and standards.
- Increase the efficiency by which Army weapon system life cycle support is provided.

- Tie together Islands of Automation [non-integrated, stand-alone, automated systems] and integrate digital logistic technical information
- Permit access to information by authorized users throughout the Army.
- Provide the capability to incorporate and use automated tools.[95]

CALS offers tremendous cost savings and increased efficiency. Integrating "Islands of Automation" and logistic technical information, while offering automated access to authorized users, are significant objectives that will be very useful to the RD&A community. The integrated systems approach, offering automated access to authorized users, would be an effective approach to integrating weapon systems users with scientists, engineers, developers and manufacturers.

#### 5. Computer Aided Weapon Systems Acquisition (CAWSA)

CAWSA is a logical, progressive, next step beyond CALS. CALS significantly improves the potential for weapon systems life cycle support, and is focused primarily on the logistics aspects of acquisition. DOD should proceed beyond the capabilities offered by CALS.

Standardization, integration and consolidation are known to be significant tools to enhance efficiency. The prospect of enhanced efficiency prompted much of the discussion regarding a "purple suit" DOD acquisition organization. The

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[95] Dr. James Tomlinson, PM, CALS, 1992.

arguments for and against such an organization are beyond the scope of this thesis; however, there are aspects of this issue that offer promise.

While it would not be good for the Services to consolidate acquisition organizations, it would be beneficial to standardize and integrate acquisition methodology, techniques, and automated acquisition tools, where feasible. One issue that is strongly emphasized in the Defense S&T Strategy is the need to integrate the user with the developer. To begin with, this is one area that could be standardized and integrated.

Standardization and integration of simulation and modelling would offer significant benefits. If the services can operate jointly in simulation and modeling efforts, they might be more effective in actual joint operations. The immediate argument that poses itself is that the Services have unique requirements in this area. The key to successful integration of complicated automated systems is in focusing on those areas that are common, and managing unique requirements by exception. Flexibility is the key.

The DOD 5000 series documents are an excellent effort toward standardizing and simplifying acquisition requirements and practices. If DOD attempts to develop a standard, integrated CAWSA, it should be done along the same lines of the 5000 series instructions. Examination of the table of contents of DOD Instruction 5000.2 (dated Feb. 23, 1991) reveals a host of areas with significant

commonality. Excluding all of the sub-areas that are common, the following is a list of the major areas where common, integrated CAWSA tools might be most beneficial:

- Acquisition Program Policies, Procedures and Documentation
- Requirements Evolution and Affordability
- Acquisition planning and risk management
- Engineering and manufacturing
- Logistics and other infrastructure
- Testing and evaluation
- Configuration and data management
- Business management and contracts
- Program control and review
- Defense Enterprise Programs and Joint Programs
- Defense Acquisition Board policies, processes, procedures and documentation

Leaders in the defense industry would probably be willing to sit down with OSD and discuss the potential benefits of integrated and standardized CAWSA. CAWSA would be like industry's CIM, only much bigger in the macro perspective.

There are many functional similarities between industry and DOD. For example, the DOD counterpart to marketing is combat development; DOD's

customer is the user; DOD's manufacturing activities are the depots, etc. There are many similarities that could be exploited.

There is a tremendous need for an expert system that captures and facilitates the sharing of lessons learned. The Services do not share information very effectively at the "worker/manager" level in acquisition. Even within a given service, commodity commands do not communicate very well at the worker level.

For example, given the standardization of the Federal Acquisition Regulation (FAR), DFARS, and Service Supplements, contracting organizations differ very significantly from organization to organization. Where flexibility is needed, this is good. Where service level and quality varies, this is bad.

The main idea here is that integration and standardization will bring increased effectiveness into the acquisition system. If the ultimate objective of the ATD concept is to produce and deploy an affordable, effective and technologically advanced weapon system, CAWSA could greatly aid in ensuring a smooth transition from ATD, to EMD, to production and support.

The scope of such an effort would be tremendous, but achievable if an integrated and modular approach were used. Perhaps the biggest impediment to developing and establishing such a system would be in getting the Services to agree on system requirements. Where disagreements occurred, OSD could appoint an arbitrator to facilitate agreement.

The chief issue here is that of empowerment. "Knowledge is power!" CAWSA would put expert systems, knowledge and tools in the hands of the decision makers and managers in the RD&A community. This is certainly an area worth studying. If DOD has not done so yet, a cost analysis should be conducted of CAWSA.

## C. THE DEFENSE SCIENCE AND TECHNOLOGY AFFORDABILITY RESEARCH CENTER (DSTARC)

As stated in Chapter III, FMS systems typically cost in the realm of $10 million to $20 million. Most manufacturers are reluctant to invest this much capital into equipment at one time. Defense contractors, given increasing uncertainty in production are even less likely to make such capital commitments.

In the FY93 Defense Authorization Bill, Congress expressed concern regarding OSD's handling of MANTECH funding requests. Apparently, OSD requested only $138 million for MANTECH; the House bill boosted this funding to $311 million. The final conference agreement resulted in the following MANTECH funding:

- Army: $51 million
- Navy: $136 million
- Air Force: $138 million
- DLA: $29 million

- OSD Agile Manufacturing: $30 million[96]

The $30 million set aside for agile manufacturing would probably only buy one to three flexible manufacturing systems, or one prototype flexible assembly system. Considering existing funding levels in the area of agile manufacturing, coupled with the large capital investment required in flexible manufacturing systems, DOD should consider methods for maximizing the use of critical resources.

As stated in Chapter III, there are Government owned FMS systems in contractor plants already, that are not being utilized anywhere near capacity. The former General Dynamics plant in Pomona, California had Government furnished flexible manufacturing cells that were very under-utilized. DOD needs to analyze how existing critical manufacturing resources are being utilized.

Initially, while developing the idea of agile manufacturing systems, and pursuing the ATD strategy, it might be more cost effective and efficient to consolidate advanced capabilities into a single activity. Therefore, DOD should establish a **Defense Science and Technology Affordability Research Center (DSTARC)**. Whether or not this concept is developed and adopted at the DOD level, the Army should establish a Service equivalent for analyzing the affordability of technologies.

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[96] News Release, HASC, pp. 12 - 13, The Defense Authorization Bill, October 1, 1992.

A DSTARC would enable execution of the "virtual company" concept, as described in the national MANTECH plan. As stated in Chapter III, "virtual companies" will be:

> . . . temporary organizations created to meet a specific need. Virtual companies are essentially "factories without walls", and consist of different organizations contributing resources to achieve a common goal. Once that goal is met, the virtual company will disband and the participating organizations will go their own ways. In addition, corporations will share production capabilities and facilities, and form joint ventures at the operational level.[97]

A DOD pilot project should be established in order to pursue affordability technology in the realm of agile manufacturing. Using the same logical approach as industry when investing in advanced FMS, the pilot project should proceed a step at a time, in an evolutionary manner. For example, when many commercial companies decide to adopt flexible manufacturing technologies, they proceed incrementally, with a strategic vision of what they eventually want to accomplish. Rather than invest in full up FMS, most companies invest in flexible manufacturing cells which they grow into FMS and CIM eventually. This approach demands strategic thinking and planning to be successful.

A pilot DSTARC (or Army equivalent) would be a vehicle for pursuing the following S&T and MANTECH objectives:

- ATD development, production and design maintenance (for SATD).

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[97] *Report to Congress on the Development of a National Defense Manufacturing Technology Plan*, p. 18, March 1992.

- Integrated Product and Process Development methodology.
- Advanced manufacturing process development (e.g., composite materials).
- Rapid prototyping research and facilities.
- Exploitation of Synthetic Environments, from the battle labs, to virtual prototyping and virtual manufacturing.
- Integration of Government acquisition and defense industry computer systems (e.g., CAWSA).
- Advanced CAPP, CAE, and CADFM systems for defense (ATD) applications.
- Exploitation of defense systems technology for dual use applications.
- Structure, organization and management of virtual companies.

A DSTARC would serve to provide the production capability, facilities, technology and expert systems that would enable the formation and operation of virtual companies in ATD projects. Companies participating as members of DSTARC virtual companies would be subscribers to technology that is developed as a part of the overall effort. Both the Government and commercial members would own the technical data rights. The potential advancements of such a US Government/industry team would be immeasurable. Perhaps the most valuable product of the DSTARC would be the R&D process itself. Expert systems would be devised to capture and promulgate learning and knowledge.

CIM, FMS and Flexible Assembly systems would be made available to the virtual companies in the manufacture of ATDs. If the decision is made to suspend

the development of an ATD, the DSTARC could serve as the activity responsible for periodic and event driven update. Communication capabilities and distributed, integrated computer systems would allow Government and industry participants to operate remotely. The staff of the DSTARC could be either Government employees, contractor operated or a combination of the two.

The DSTARC should be required to compete with industry to provide facilities for virtual companies to operate in ATD projects. Many of the same control systems (e.g., C/SCSC) would also be applied. Expert systems might also be developed to provide rapid, resource and cost estimates for ATD projects.

One ultimate objective of the DSTARC would be its own evolution into a Government and industry team/organization, advancing dual use technologies and enhancing US industrial, global competitiveness. The long range goals and objectives of the DSTARC should be established by a strategic planning process, involving all of the key stakeholders. Industry and professional organizations like (SME, IEEE, SEI, ANSI, ISO, etc.) should be invited to participate and subscribe. The key to success in the planning, development and implementation of the DSTARC lies in ensuring long range, strategic thinking and vision, <u>early and throughout</u> the project.

Enhanced dual use technology development, industrial base visibility, capitalization of advanced manufacturing processes and systems, increased standardization, and aggressive US global economic competition would be just a few

of the major advantages of the DSTARC concept. The only great disadvantage would be the increased funding necessary to accomplish DSTARC objectives. However, an incremental and centralized approach to funding the project would be most feasible.

The world is changing rapidly. Global competition is increasing by orders of magnitude. The US defense budget is shrinking almost as quickly. The time has come for the United States Government to take steps to team up with US industry and set new technological and quality standards in globally competitive markets. The DSTARC concept would be a step, albeit a small one, in the right direction.

# VI. CONCLUSIONS AND RECOMMENDATIONS

## A. CONCLUSIONS

### 1. General Conclusion

The new flexible acquisition strategy (ATD) adopted by DOD is a realistic approach to future RD&A efforts. It realigns acquisition baseline priorities by realistically balancing cost with schedule and performance concerns. As a part of this new flexible acquisition strategy, the reconstitution concept requires introduction of innovative approaches to ensure ultimate producibility of weapon systems in the event of an emerging threat to national security.

Rapid advances in manufacturing and information technologies offer potentially significant improvements in future RD&A efforts. Science and Technology (S&T) thrusts oriented on exploiting these technological advances should prove to be cost effective in the long run. R&D in the areas of advanced manufacturing processes, technology for affordability and synthetic environments offers significant near term and long range cost benefits to DOD, and ultimately the American taxpayer.

Computer aided design and analysis systems integrated with both modelling and simulation systems, and flexible manufacturing systems, offer very

significant capabilities to the RD&A community. Virtual reality based systems introduce a highly effective communications vehicle, linking users with developers, scientists, engineers and manufacturers.

The concurrent engineering design team methodology, emphasizing design for manufacturability (DFM) and life cycle cost early and throughout ATD system design and development, will enable and optimize advanced technology efforts. This approach to RD&A requires a significant paradigm shift regarding the integration of product and process development.

### 2. Specific Conclusions.

**When producibility is not considered early and throughout the development of a weapon system, significant problems will probably arise.** The A-12 is an excellent example of a weapon system program that failed, at least partially, due to a lack of producibility goals and standards in the design process. Another part of the problem was due to a sequential engineering, rather than a concurrent engineering approach. The result was a program that was over cost, behind schedule and subsequently cancelled.

**One benefit of the new ATD process is improved producibility based on extended development periods.** With the dissipation of the Soviet threat, the intense pressure to field an advanced system, as quickly as possible, has subsided. This will

provide more time to devote to fully developing advanced manufacturing processes to support new technologies.

**Any materiel R&D program must incorporate a concurrent engineering approach involving DFM to be successful in fiscally constrained times.** This allows integration of all critical design issues, up front, when the greatest potential to influence system characteristics exists.

**"Technology in the laboratories will not win future engagements."** Advanced technologies are crucial in maintaining superior forces, insofar as they can be produced, fielded and supported. Scientists and engineers must not lose sight of the primary purpose of the Defense S&T Strategy — to put technologically advanced weapon systems into the hands of soldiers, airmen, sailors and marines.

**The capability to manufacture a prototype does not guarantee the capability to produce it in significant numbers.** Processes used to manufacture a significant quantity of a weapon system are different than those used to produce a prototype. Full rate production process capabilities should be considered up front in a design.

**DOD should be cautious regarding dependence on the concept of flexible manufacturing systems.** While great strides have been made in DNC integrated systems, much work remains to be done in flexible electronics and flexible composite manufacturing technologies.

**The new ATD policy is not clear in all development situations.** The new S&T strategy does not define the concept of demonstrated "fully matured" technologies very well. It is not clear when some work still needs to be done on some manufacturing processes in an ATD. Nor does the new strategy provide guidance regarding the disposition of an ATD when the military need for a weapon system or technology is not immediately identifiable.

**The development of simulations and synthetic environments is critical to the success of the new flexible acquisition strategy.** Virtual prototyping is a much more cost effective and time saving method of iterative development, than the concept of physical prototyping and Test-Analyze-Fix-Test (TAFT). This technology also improves developers' capabilities in analyzing designs and integrating a concurrent engineering approach.

**Simulation networks have the potential to serve as an effective communications vehicle in weapon systems development.** This tool has the potential to improve the interface between the users, scientists, developers and manufacturers. However, much work remains to be done in integrating these systems and functions.

**Computer aided design (CAD) is the critical technology that enables cost effective ATD modeling.** This opens the door to other computer aided applications like CAE, CAPP, and CADFM. CAD is the first step toward ensuring system

manufacturability. It also aids connectivity between the user and the development/manufacturing community.

**Computer Integrated Manufacturing (CIM) has tremendous potential in weapon systems RD&A efforts.** The Society of Manufacturing Engineers sees CIM as "a key ingredient in improving the productivity, efficiency, and profitability of the US industrial base and in regaining a competitive position in the world marketplace." These same improvements will be shared by the Government, and ultimately the taxpayer, in developing and manufacturing weapon systems. It is also important to realize that CIM is a philosophy and cannot be purchased; it requires a significant paradigm shift regarding the normal conduct of business in a manufacturing enterprise.

**The CIM concept could be expanded in designing and developing an integrated Computer Aided Weapon Systems Acquisition System (CAWSA).** Such a system could include all activities from the perception of a threat, the determination of the need for a materiel solution and requirements generation; through concept exploration, simulations, virtual prototyping, virtual manufacturing, demonstration and validation or ATD, and EMD; and on through production, fielding and life cycle support of the system.

**Flexible Manufacturing Systems (FMS) offer a significant potential for achieving S&T affordability objectives.** Integrated manufacturing systems offer

tremendous improvements in efficiency and flexibility. The idea of using FMS to "decouple cost from volume" is valid when looking at low rates of production; however, it is important to realize that there are still significant costs associated with manufacturing the first item.

**Existing, Government owned, FMS are currently being under-utilized.** An excellent example of a significantly under-utilized FMS was at the former General Dynamics Plant located in Pomona, California. These critical resources might be better utilized if consolidated for use by virtual companies' ventures.

**The concept of Agile Manufacturing is feasible.** Modularity of manufacturing cells and FMS makes it feasible to provide total factory floor agility. The CIM concept makes it possible to integrate all of these capabilities.

**The idea of developing a "virtual factory" to reduce manufacturability risk is achievable.** CAD, CAM, CAE, GT, CAPP, FMS and CIM all lend themselves to the success of this concept. The distinction between a "virtual factory" floor and a real factory floor becomes insignificant with CIM database capabilities.

**Including DFM early in ATD development has several potential benefits.** Most significant are minimization of overall development costs, reduced system development and deployment time, and smooth, efficient transition to production.

**Many problems will result in ATDs developed without incorporating DFM.** Increased development and production time will ultimately increase program costs.

Exacerbating cost and schedule effects are increased dependence on specialized production equipment, diminished quality, difficulty in factory automation, expert systems and integration, and difficulty implementing Just-in-time (JIT) material supply practices. The most significant defense industrial base effects are decreased global competitiveness and less dual use technological applications.

**DFM offers many significant benefits.** In addition to development cost savings, DFM can also improve system operational performance, RAM and ergonomic design. Industrial benefits include ease of assembly, and improved testability, safety considerations, environmental impact and machinery utilization. Reduced materials overhead during manufacturing, and reduced repair parts inventory required for support, offer significant additional cost savings.

**Producibility Assessment (PA) is an effective quantitative tool that can enhance the design process.** PA can be used to develop overall system producibility, from the part level, all the way up to the weapon system level. PA provides a good measure of the risk associated with given design alternatives and decisions.

**Suspending ATD development (SATD) would probably have the following effects on system producibility:**

- *Decreased risk involving advanced manufacturing processes.* The time lapse while a system is suspended should improve the maturity of advanced manufacturing process capabilities in the defense industry.

- *Material, part, component and subsystem obsolescence.* In those technologies characterized by rapid growth (e.g., electronics) the potential for obsolescence,

caused by manufacturing process and market changes, increases as a function of time suspended. This could also result in concomittant design obsolescence.

- *Significant adverse effects on the lower tier defense industrial base.* In order to remain in the defense sector, lower tier manufacturers need to produce. Not proceeding with production effects lower tier manufacturers the most.

**Standardization is essential to effective integration.** Many military standards are counter-productive to integration efforts. ISO 9000 and standard commercial practices provide a good basis for integrated design and flexible manufacturing systems. Standardization is required to effectively implement DFM.

**Computer Aided Acquisition and Logistic Support (CALS) offers major cost savings and increased efficiency.** Integrating "islands of automation" and logistic technical information, while offering access to authorized users is the same approach that could be adopted to integrate weapon systems' users with scientists, engineers, developers and manufacturers.

**Computer Aided Weapon Systems Acquisition (CAWSA) is feasible and achievable using a modular, incremental approach.** CAWSA would be most useful if developed according to DOD 5000 series functional areas. Standardization of acquisition tools would lead to simplifying acquisition requirements and practices. Integration of acquisition tools would lead to significant increases in productivity and cost effectiveness.

**DOD has a need for an activity that would provide the production capability, facilities, technology and expert systems to enable the formation and operation of**

**virtual companies in ATD projects.** The DSTARC concept would be an effective integrated approach to achieving S&T affordability objectives. Funding for such a project would require an incremental approach. The design and plans for a DSTARC would be most effective if developed using the strategic planning process.

## B. RECOMMENDATIONS

There a several recommendations that can be drawn from the previous conclusions. In order to ensure effective implementation of the ATD and reconstitution concepts, DOD must pursue advanced technology enabling methodologies, enhanced systems integration, increased standardization, and optimized use of critical resources. The following are specific recommendations that DOD should consider.

**A concurrent engineering approach, incorporating DFM concepts, should be used early and throughout all ATD projects.** This approach will provide significant benefits to DOD. DFM is an effective tool for ensuring that engineers "stick to good enough" in ATD design. Ultimately, producing and deploying an affordable and effective weapon system is the objective of the ATD concept.

**Producibility Assessment methodology should be incorporated into all ATD design processes.** This will provide an effective, quantitative tool for analysis and decisions in ATD design.

**DOD should clarify the alternatives and decisions involved in the ATD process.** Clear guidance regarding the disposition of an ATD, when the military need for a weapon system or technology is not immediately identifiable, would aid in planning and executing ATD projects. Specifically, DOD should clearly define the concepts of suspended ATD development (SATD) and its role in the reconstitution concept.

**Integrated computer aided (expert) systems development technologies should be exploited where they are feasible.** DOD should analyze the feasibility and cost effectiveness of CAWSA.

**The "Ten Commandments of CE" should be applied in all ATD projects.** This will result in significant increases in efficiency, performance and cost effectiveness.

**DOD should exploit methods for effectively integrating scientists, engineers, developers, and manufacturers into user simulation networks.** Simulation networks have the potential to significantly enhance development of the weapon systems of the future. Integration of all of the "key players" is paramount.

**DOD should analyze the potential benefits of adopting ISO 9000 standards throughout defense acquisition.** Wherever possible, common industry practices need to be incorporated into the design of an ATD if it is to be optimally and ultimately producible. DOD must critically analyze the current system of military standards.

**DOD should analyze the use of Government owned FMS throughout the defense industrial base and depot system.** Under-utilized equipment should be

prioritized and consolidated where feasible. As a part of the FMS emphasis, DOD should consider the liberalization of Government equipment utilization regulations, in order to stabilize the lower tier defense industrial base.

**DOD should analyze the potential cost effectiveness and feasibility of the Defense Science and Technology Affordability Research Center (DSTARC) concept.** DSTARC would be an effective integrated approach to achieving S&T affordability objectives. A strategic planning approach should be used in DSTARC design and plans, if the decision is made to use any of the DSTARC concept. The Army should similarly analyze the feasibility of a Service DSTARC equivalent.

## C. AREAS FOR FURTHER RESEARCH

The following are areas should be investigated for potential benefit to DOD.

- **Computer Integrated Expert Systems in Acquisition.** There are a significant number of issues that should be explored in this rapidly changing area of manufacturing and information systems technology. Detailed research needs to be conducted regarding integration of synthetic environments with industry expert systems and potential acquisition community expert systems.

- **CE Development Methodology vs. Sequential Engineering Development Methodology.** Research of the specific baseline effects in this area would be useful to the acquisition community. It would serve to provide information to acquisition community decision makers and managers regarding the potential advantages and disadvantages of this methodology.

- **ISO 9000 Standards in Defense Systems Acquisition.** Much research needs to be done in this area in order to effectively pursue the new Defense S&T strategy involving advanced technologies for affordability. An in depth analysis of the advantages and disadvantages of adopting ISO 9000 standards would help clarify this issue for key DOD decision makers. Integration of product and

process development, implementation of agile manufacturing objectives, improving the potential for dual use technologies and enhanced US industrial competitiveness in the global market will require adoption of international standards. Defense acquisition decision makers need more information in this critical area.

- **Virtual Prototyping, Virtual Manufacturing, Virtual Companies, and Virtual Acquisition transition to Agile Manufacturing.** The potential capabilities for increased cost efficiency developments in this area appear limitless at this time. There is a significant need for directed, focused research in this rapidly evolving technological realm.

- **Design and Implementation of CAWSA and DSTARC.** This thesis has proposed two concepts with a focus on improving the producibility (affordability) of ATDs. A detailed analysis of alternative designs and implementation issues in these areas would be useful to acquisition community decision makers.

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The effects on weapon systems' producibility of suspending system development after Advanced Technology Demonstration (ATD).